Motor Skills, Cognitive Skills and Executive Functions in Preschool Children

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Summary

Motor skills, cognitive skills and executive functions are fundamental for healthy development; they are necessary for processing information, daily activities, social participation, and the regulation of thoughts and behavior. The aim of this thesis was to extend knowledge of the stability and predictors of motor and cognitive skills, executive functions, and their associations in preschool age. Our research in typically developing preschool children showed that motor inhibition and cognitive inhibition were related and may depend on cortical maturation. Both motor and cognitive skills showed high intra-individual stability and, thus, might predict motor and cognitive performance later in childhood. Moreover, motor skills seem to be a predictor for cognitive and executive performance. Other factors that predicted executive functions were biological and demographical, but these are less easily modified. This finding may indicate that the potential to influence development through prevention and intervention might be only limited. To exhaust the limited potential, interventions for supporting development should be targeted and thus focus on children at risk.

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Zusammenfassung

Motorische und kognitive Fähigkeiten, sowie exekutive Funktionen sind grundlegend für eine gesunde Entwicklung eines Kindes. Sie ermöglichen die Verarbeitung von Informationen, alltägliche Aktivitäten, soziale Partizipation und die Kontrolle von Gedanken und Verhalten. Das Ziel dieser Dissertation war es, das Wissen über Stabilität und Prädiktoren von motorischen und kognitiven Fähigkeiten und exekutiven Funktionen im Vorschulalter zu erweitern, sowie den Zusammenhang zwischen den drei Fähigkeiten zu untersuchen. Unsere Studien mit normalentwickelten Vorschulkindern haben gezeigt, dass motorische und kognitive Kontrolle zusammenhängen und wahrscheinlich beide von der kortikalen Reifung abhängen. Sowohl die motorischen als auch die kognitiven Fähigkeiten zeigten eine hohe intraindividuelle Stabilität und sagen die motorische und kognitive Fähigkeit später in der Kindheit voraus. Darüber hinaus scheinen motorische Fähigkeiten ein Prädiktor für kognitive und exekutive Leistungen zu sein. Andere Prädiktoren, die exekutive Funktionen voraussagten, waren biologische und demographische Faktoren. Dieses Ergebnis, dass nicht veränderbare Faktoren exekutive Funktionen am besten voraussagten, deutet darauf hin, dass ein Einfluss von aussen durch Prävention und Intervention begrenzt ist. Um den begrenzen Einfluss auszuschöpfen sollten Massnahmen zur Unterstützung der Entwicklung zielgerichtet sein und primär auf gefährdete Kinder ausgerichtet werden.

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Introduction

Motor skills, cognitive skills, and executive functions (EFs) enable processing information, daily activities, social participation, and the regulation of thoughts and behavior. They are thus fundamental factors in children's development. To ensure the optimal and healthy development of children, we need to know the developmental course, factors influencing development, and the connections between these factors. In this way, we can identify potential risk and protective factors and initiate prevention and intervention accordingly. Early childhood is a sensitive period during which certain fundamental health indicators are particularly open to influence. To extend knowledge about the stability of development, influencing factors, and associations of motor skills, cognitive skill, and EFs, these factors were studied in preschool aged children through the Swiss Preschoolers' Health Study.

The next section describes the overall aim and study design of the Swiss Preschoolers' Health Study. Following this, motor skills, cognitive skills, and the construct of EFs are defined, and the relevance of and interrelation between these domains are introduced. At the end of the introduction, the research questions are presented. The articles that assessed these questions follow.

3.1 Swiss Preschoolers' Health Study – SPLASHY

The background and design of SPLASHY is described in detail in the study protocol by Messerli-Burgy et al. (2016). A summary is presented here.

3.1.1 Background of SPLASHY

For the first time in history, children have a shorter lifespan than their parents due to obesity and noncommunicable lifestyle-related chronic disease ("WHO: Childhood overweight and obesity," 2009). Improving children's overall health represents a major

> goal for researchers, practitioners and policy makers. General health in young children includes high levels of cognitive skills and social skills, psychological well-being, a healthy body weight, and well developed motor skills. These domains can be summarized as the child's thinking, feeling, behaving, eating, growing and moving in an optimal way, even under challenging conditions. Stress and lack of physical activity (PA) represent two relevant health challenges in today's modern environment that may interfere with children's health (Heim & Binder, 2012; Reilly, 2010). Exposure to environmental stressors (ranging from major severe life events to daily stress) is omnipresent. On the other side, lack of physical activity has become the 4th leading cause of death worldwide. To better elucidate the impact of these two factors, alone and in combination, on children's health, prospective studies starting in young children are needed (Messerli-Burgy et al., 2016, p. 2).

Thus, the aim of the SPLASHY study is to examine the effect of physical activity and stress on physiological and psychological health in preschool children. In addition to physical activity and chronic and acute stress levels, other factors were assessed, such as the environment of the child, childcare characteristics, parenting style, and major life events. Physiological and psychological health were operationalized as cognitive functioning, motor skills, body composition, and psychosocial well-being.

3.1.2 Method and Design of SPLASHY

SPLASHY is a multi-site, prospective cohort study that includes healthy children at preschool age in two sociocultural areas of Switzerland, the German-speaking and French-speaking regions. Children were recruited from 84 child care centers in five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, and Zurich). These cantons together comprised 50% of the Swiss population in 2013. Recruitment for this study started in January 2013, and testing for baseline measurement (T1) began in March 2014. One year later, the first follow-up measurements (T2) took place. SPLASHY is a SINERGIA project of the University Hospital Lausanne, University Fribourg, University Zurich, and the University Children's Hospital Zurich. The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud, the main ethical committee) and is in accordance with the Declaration of Helsinki. Parents provided written informed consent.

Recruitment of child care centers took place from January 2013 to October 2014. The selection procedure for the recruitment of child care centers was stratified according four levels: urban and rural community with high socioeconomic status (SES) (above-average) and low SES (below-average), each based on the prevalence of child care centers in the respective communities. In sum, 639 child care centers were contacted to provide information for the SPLASHY study (Figure **1**). Of these, 126 child care centers responded positively and agreed to inform the parents about the study. The main reasons for non-participation of the child care center in the study were lack of time (26 %), too few (less than 4) children of the required age range present in child care (21 %), no interest (21 %), and organizational changes (13 %).

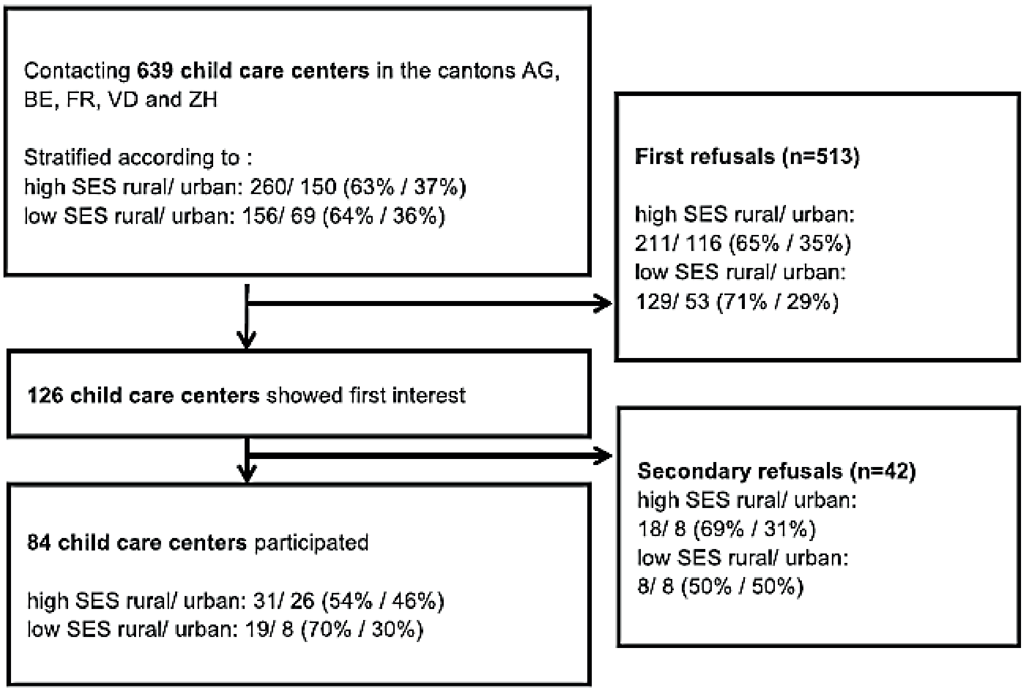

Figure 1. *Recruitment of child care centers and refusals for participation including SES distribution (from Messerli-Burgy et al., 2016).*

3.1.3 Participants

In total, 555 children were tested. In the first wave in 2014, a first measurement point (T1) tested 476 children. From these children, 382 (20% drop out) could be tested one year later at a second measurement point (T2), in the second wave in 2015. In 2015, we tested an additional T1 of 79 new children to compensate for the drop-out. The sample of these 79 children assessed in 2015 for the first time was slightly younger (0.23 years based on mean) than the sample of the 476 children measured in 2014 for the first time. Therefore, the data for the 79 new children were added to the first wave and their scores for the second wave imputed. The age range of all children at T1 was 2.2 – 6.6 years (M = 3.9, SD = 0.7). In the total sample of 555 children, gender was nearly equally distributed between 293 boys and 262 girls.

3.1.4 Procedure

The participants were tested in the children's child care centers on three afternoons. On the first afternoon, a motor test was performed and body composition measured; on the second afternoon, self-regulation, executive, and cognitive functioning were assessed; and on the third afternoon, a stress reaction test was executed (Figure **2**). Each child was tested individually. All examiners were trained in all tests, and quality checks were performed periodically. In addition to the assessment in the childcare centers, the children wore an accelerometer over a week to measure physical activity, and parents took saliva samples at home to gather the stress level of the children. Moreover, the parents completed a questionnaire on general health about anamneses of the child and demographic and environmental information about the family and validated questionnaires on psychological well-being about characteristics of the child and parenting style. All questionnaires could be completed online, or if desired on paper. Table **1** provides an overview of all measurements. More details on the variables and statistical analysis used in this thesis are presented in the articles in Chapter 4.

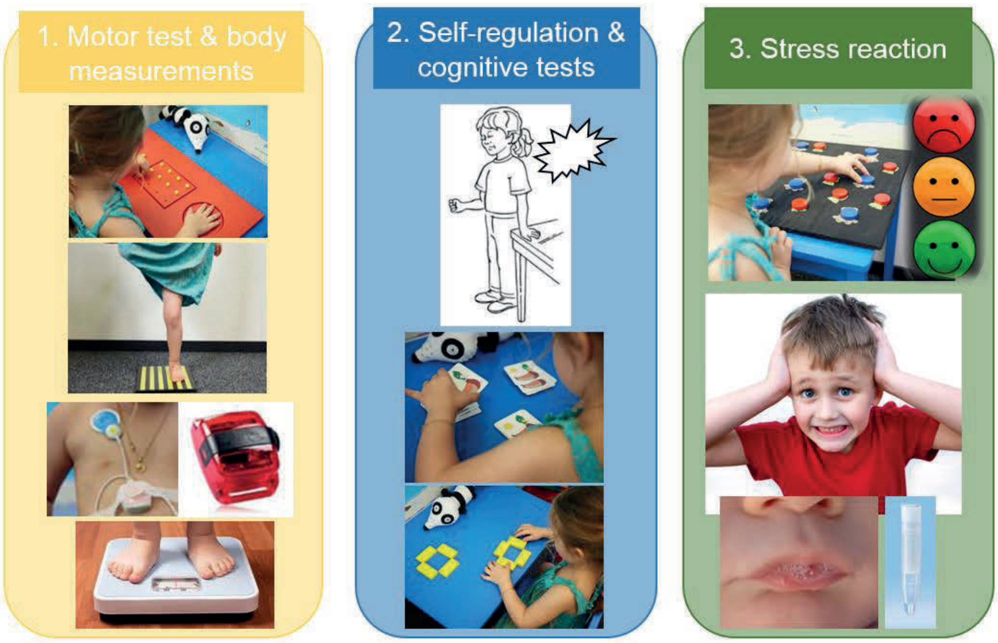

Figure 2. *Measurements of the SPLASHY study on the three testing afternoons.*

Table 1. *Outcomes and measures. Children's direct and indirect (parent and child care educator assessment) (adapted from Messerli-Burgy et al., 2016)*

Measures	Tool	Informants
Children's direct assessment at the child care center		
First afternoon:		
Adiposity	BMI, sum of four skinfolds, waist circumference child	child
Motor skills	Zurich Neuromotor assessment (ZNA3–5)	child
Second afternoon:		
Cognitive functioning	Intelligence and Development Scales-Preschool (IDS-P) – 4 cognitive tests	child
Self-regulation	Statue test (NEPSY)	child
Third afternoon:		
Stress response/acute stress reactivity	Adaptation task with stress perception, behavioral responses, salivary amylase & cortisol, HR & HRV, Picture Stress Test	child
Indirect assessment by parents or child care educator		
Major life events, chronic day-today stressors, SES, neighborhood, lifestyle, pre-& perinatal conditions, birth weight, breastfeeding, early regulatory problems, general health, reported PA	General health questionnaire	parents
Parenting style	Alabama Parenting Questionnaire (APQ)	parents
Parental stress	Parental Stress Scale (PSS)	parents
Children's eating behavior	Children's Eating Behavior Questionnaire (CEBQ)	parents and child care educators
Children's mood and behavior problems	Strengths and Difficulties Questionnaire (SDQ)	parents
Children's temperament	Emotionality Activity Sociability Temperament Survey (EAS)	parents
Children's emotion regulation	Index combining EAS scales, observed emotion regulation behavior, salivary cortisol, HRV during adaptation task	parents and child
Family atmosphere	Parental Expressed Emotions by Five-Minute Speech Sample (FMSS)	parents
Social contacts (with peers)	Child care questionnaire	child care educators
Physical activity	Accelerometers	child
Physiological stress responses in the chronic setting	Salivary amylase & cortisol, clipped fingernails, HR and HRV	child

3.2 Definition of terms and constructs

3.2.1 Motor skills

Motor skills (also called *movement skills*) are defined as observable, “goal-directed movement patterns” (Burton & Miller, 1998, p. 43). Motor skills can be distinguished from *motor abilities*, which are “general traits or capacities of an individual” (Burton & Miller, 1998, p. 43) that underlie the performance of skills. In contrast to *skills*, *abilities* are scarcely modifiable though training and found to be quite stable. *Motor performance* is “goal-directed movement that can be described in terms of quantity or quality” (Burton & Miller, 1998, p. 43). While quantity focuses on the product of the performance, quality focuses on the process of movement (Burton & Miller, 1998). Measures for motor quality are for example *associated movements*. Associated movements appear on the contralateral site of the body during a voluntary movement and are considered to be indicators of the maturation of the motor nervous system (Hoy, Fitzgerald, Bradshaw, Armatas, & Georgiou-Karistianis, 2004).

Motor development can be defined as “adaptive or functional changes in movement behavior over the life span” (Burton & Miller, 1998, p. 44), which are due to maturation, growth, and experience and therefore involve changes in motor skills and motor abilities (Burton & Miller, 1998). The distinction of these two terms is important but not always clear; because motor abilities underlie motor skills, hence abilities are part of skills. Further, the literature uses a broad range of additional terms which cannot always be characterized as either skills or abilities. In the following, the term motor skills is primarily used for overall motor skills except when referring to specific skills or abilities.

Motor skills are essential for the healthy development of children: first, because motor skills are necessary for daily activities and, especially in childhood, for social participation (e.g., playing games with peers). Second, motor skills are interrelated with a number of other developmental domains such as perception, language, cognition, and social and physical development (Bar-Haim & Bart, 2006; Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Diamond, 2000, 2007; Iverson, 2010; Rosenbaum, Carlson, & Gilmore, 2001). Children with impaired motor skills have often been found to score lower in cognitive tasks (Michel, Kauer, & Roebers, 2011a; Michel, Roethlisberger, Neuenschwander, & Roebers, 2011b). Motor competence is important for social participation and daily activities. Thus, impaired motor skills can lead to social exclusion, poorer self-esteem, and less physical activity, which in turn can influence physical health (e.g., cardiorespiratory fitness, muscular strength and body weight: (Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Smyth & Anderson, 2000).

3.2.2 Cognitive skills

"Cognition refers to the processes or faculties by which knowledge is acquired and manipulated" (Bjorklund, 2005a, p. 2). More specifically, cognition concerns mental processes involving perception, learning, memory, and reasoning. *Cognitive skills* and *cognitive functioning* are by definition mental processes and thus, cannot be observed directly and have to be inferred from observed behavior (Bjorklund, 2005a). Such observable behavior includes, for instance, the amount of time a newborn spent watching a stimulus or the number of words a child can remember. The mechanisms that underlie this behavior are thereby partly conscious but also partly unconscious (Bjorklund, 2005a). Cognitive skills include basic mental processes such as encoding and classifying a stimulus and such higher order processes as solving a problem, evaluating a situation and modify a behavior. These higher order processes are often described as EFs (see Chapter 3.2.3). In this thesis, cognitive skills refer to basic cognitive processes, such as perception, attention, memory, and reasoning.

Cognitive development—as well as development in general—has a biological component; therefore, the overall process is predictable and similar between individuals (e.g., most children learn their first words between 12 and 18 months, and most children recognize themselves in the mirror only after 18 months (Largo, 2002; Largo, Molinari, Comenale Pinto, Weber, & Duc, 1986). However, the interaction between external factors, such as experience, is crucial and can lead to individual differences. Bjorklund (2005a) described this relationship: experience (external factor) affects the child's developing intellect, which in turn affects that child's actions (individual factor). Jean Piaget argued similarly when he stated that the activity, in form of physical exploring, of the child is necessary for reaching the next cognitive stage (as cited in Kail, 2004a).

Cognitive skills are fundamental for healthy development because they guarantee the 'thinking' of children. Thinking means the mental processing of information that includes perception, attention, storage, remembering, and initiating acting. Thus, cognitive skills are crucial during development for processing new information, learning about the environment, and enabling higher cognitive processes. This concerns not only knowledge of facts but rules and concepts of social interactions too.

3.2.3 Executive functions

No unique definition exists of EFs. EFs are considered to be top-down control processes that regulate cognition, thoughts, and behavior (Miyake & Friedman, 2012). One might also describe EFs as the "result of coordination of simpler [cognitive] skills" (Garon, Bryson, & Smith, 2008, p. 49). EFs are needed for problem solving, planning, and goal-directed behavior; they enable inhibition of irrelevant stimuli and inappropriate behavior and enable automatic thoughts and responses to be overridden (Diamond, 2013; Garon et al., 2008; Miyake & Friedman, 2012). The three main components of EFs have been identified as inhibition, working memory, and cognitive flexibility (Garon et al., 2008; Miyake et al., 2000). Executive processes are primarily located in the frontal cortex and develop with maturation (Diamond, 2013; Garon et al., 2008; Miyake et al., 2000). In comparison to other brain regions, the "development and maturation of the frontal cortex proceed more slowly. Whereas neuronal density in the primary visual cortex reaches adult levels by 4 to 5 months, neuronal density in the frontal cortex fails to reach adult levels even at 7 years of age" (Squire et al., 2008, p. 1041).

EFs in preschoolers have been shown to predict early academic performance (Cameron et al., 2012; Mulder, Verhagen, Van der Ven, Slot, & Leseman, 2017; Roebers et al., 2014). Moreover, EFs in children have been interrelated with social interactions (Devine & Hughes, 2014; Moriguchi, 2014) and linked in adolescents and adults to externalizing behavioral problems, attentional deficit, substance use, job success, and marital harmony (Bailey, 2007; Eakin et al., 2004; Miyake & Friedman, 2012; Sawyer, Miller Lewis, Searle, Sawyer, & Lynch, 2015; Young et al., 2009).

A central aspect of EFs represents inhibition (Diamond, 2013; Garon et al., 2008). Inhibition refers to the ability to actively suppress certain thoughts and behaviors at specific times (Bjorklund, 2005d). In domains related to EFs, lack of inhibition skills mostly lead to a negative outcome (e.g., attentional deficit, hyperactivity, substance abuse: (Young et al., 2009)).

3.3 Relationship between motor skills, cognitive skills and executive functions

The previous three chapters defined motor skills, cognitive skills, and the construct EFs and indicated that these skills all play an important role in daily life and development of children. Moreover, it is assumed that these skills are interdependent. However, the examination and understanding of the associations between motor and cognitive skills and EFs is still ongoing.

3.3.1 Motor skills and cognitive skills

Piaget (1896 – 1980), who established the field of cognitive development, hypothesized that activity in the form of physical exploring is necessary for reaching the next cognitive stage (Bjorklund, 2005c; Kail, 2004a). He described children as intrinsically active, which leads them to be “active initiators and seekers of stimulation” (Bjorklund, 2005c, p. 80). In infants and toddlers, it might be reasonable that grasping and exploring an object with a body part (e.g., hands, mouth) might lead to extended knowledge and understanding of the object. However, Piaget did not specify the role of motor skills later in development. Since then, many studies have investigated the association between motor skills and cognitive skills during early and late childhood, and there is still great scientific interest in this field (Davis, Pitchford, & Limback, 2011; Diamond, 2000; Jenni, Chaouch, Caflisch, & Rousson, 2013; Piek, Dawson, Smith, & Gasson, 2008; Roebers & Kauer, 2009).

Results from empirical studies have differed regarding the association between motor and cognitive skills. In a study with toddlers, overall motor ability and cognitive ability were positively correlated with each other at age one ($r = .55$, $p < .01$). At age two, fine motor skills correlated with cognitive ability ($r = .46$, $p < .01$), but not gross motor skills. No significant predictive value of motor ability was found at age one for cognitive ability at age two ($r = .21$, $p <.10$) (Wu, Liang, Lu, & Wang, 2017). In a study with 4-to-11-year-old children by Davis et al. (2011), overall motor and cognitive skills were moderately positively correlated in the whole sample. Additionally, these authors discovered that the correlations were mainly due to the association of visual processing and fine manual control. Piek et al. (2008) examined the predictive value of motor und cognitive skills in a small sample of 33 children from birth to four years on later outcomes in school age. They found, as one of the only studies, that early gross motor skills predicted cognition outcome, while early fine motor skills did not predict either fine motor skills or cognition. In a study by Roebers et al. (2014) with 169 five-to-six-year-old children, fine motor skills predicted IQ one year later, with a small effect size. Further studies with preschoolers and school-aged children have found weak to strong positive correlations between specific aspects of the two domains in school-aged children and adolescents (Ahnert, Bös, & Schneider, 2003; Jenni et al., 2013; Roebers & Kauer, 2009; Wassenberg et al., 2005). For instance, qualitative and quantitative aspects of motor performance correlated with visual motor integration and working memory (Wassenberg et al., 2005). Van der Fels et al. (2015) provided an overview of correlations between motor and cognitive skills in typically developing children. Total motor scores were mostly not correlated with cognitive tasks, object control tasks were weakly correlated with visuospatial working memory, weak to moderate correlations were found between bilateral body coordination and fluid intelligence, gross motor tasks were not or were only weakly correlated with cognitive tasks, and moderate and strong correlations with visual processing were reported for fine motor skills. These authors concluded that the more complex motor and cognitive tasks are, the more strongly they are correlated, supporting the hypothesis of common underlying processes.

In clinical samples (e.g., preterm-born children or children with low birth weight), it has been observed that motor and cognitive impairments occurred simultaneously (Kaplan, N. Wilson, Dewey, & Crawford, 1998; Michel et al., 2011b; Seitz et al., 2006). For example, in very low-birth-weight-born children, motor and cognitive performance were lower than in normal-weight-born children, and deficits in certain domains were correlated, especially in the visuomotor domain (Seitz et al., 2006).

In sum, several studies have reported that overall motor skills and cognition are in general two separate domains, although specific connections between these two domains have been found (Davis et al., 2011; Jenni et al., 2013; Roebers & Kauer, 2009; Wassenberg et al., 2005). Moreover, some evidence exists that motor skills predict later outcome of cognitive performance. Explanations for an association can be summarized in three points. One explanation for an association between motor and cognitive skills stems from neuroimaging studies, which have found co-activations between the prefrontal cortex, the cerebellum, and basal ganglia (Diamond, 2000; Leisman, Braun-Benjamin, & Melillo, 2014; Schmahmann & Caplan, 2006). Diamond (2000) stated that the longstanding assumption that the prefrontal cortex is primarily linked to cognitive functions and the cerebellum to motor performance is no longer tenable. Schmahmann and Caplan (2006) reported that the cerebellum contributes not only to motor control but also to cognitive processing and control of emotions. A second explanation is that motor and cognitive skills both develop during a similar time span, are acquired in comparable ways, show similar learning stages, and have related training effects (Rosenbaum et al., 2001). A third explanation is that underlying processes might be shared. It is assumed that in complex tasks, which require higher demand, motor and cognitive tasks share common underlying processes, which enable information processing, organization of behavior, and attention to or inhibition of irrelevant stimuli (Livesey, Keen, Rouse, & White, 2006; Roebers & Kauer, 2009; Wassenberg et al., 2005). These processes are the result of higher-order cognitive skills often attributed to EFs. Thus, the performance in complex tasks may rely on EFs. Leisman, Moustafa, and Shafir (2016, p. 8) reported that "motor and cognitive functions require the learning of sequential actions. These sequences are most optimized with control by specialized network mediated by both executive function and automaticity".

3.3.2 Motor skills, cognitive skills and executive functions

Little is known about the origins of EF development, but it is assumed that they develop in early infancy in a hierarchical manner from simple abilities to more complex ones (Garon et al., 2008).

For example, the ability to inhibit a response develops within the first year of life and involves a motor component (e.g. suppress to touch an object) (Garon et al., 2008). Therefore, in young children, motor inhibition might be linked to or even be a requirement for behavior control. Accordingly, Gottwald, Achermann, Marciszko, Lindskog, and Gredebäck (2016) postulated that EFs are "grounded in an infant's developing ability to control and plan motor actions" (p.1601). In fact, these authors found that in a cross-sectional study of 18-month-olds, better prospective motor control was positively correlated with better inhibition (not touching an object) and working memory (r = .31 – .39), but not with fine or gross motor skills. Prospective motor control was measured as peak velocity when reaching an object; high movement velocity was an indicator of high prospective motor control.

Recently, Wu et al. (2017) investigated the assumed relationship between motor abilities (fine and gross motor skills), cognitive abilities at the age one and two years, and EFs (working memory and cognitive and emotional inhibition) at three years of age. Motor and cognitive abilities at age one were unrelated with all three EFs tasks at age three. Fine motor skills at age two were correlated with working memory at age three (r = .23, p < .05), and both fine and gross motor skills were correlated with cognitive inhibition control at age three (r = .30/.41, p < .01). Cognitive ability at age two was only correlated with working memory at age three (r = .36, p < .01). When sex and SES were controlled for in a regression model, these two factors accounted for 2–12% of variance in EFs (2% cognitive inhibition, 9% emotional inhibition, 12% working memory). Motor and cognitive abilities explained further 1– 4% variance at age one and an additional 4– 16% at age two.

Mediation models that examined the indirect path from motor ability to cognitive inhibition control via cognitive ability and working memory found that motor ability at age one predicted cognitive inhibition at age three only via the indirect path (Model 1.1, Figure **3**). However, at age two, fine and gross motor skills predicted cognitive inhibition control directly (Model 1.2 and 1.3, Figure **3**).

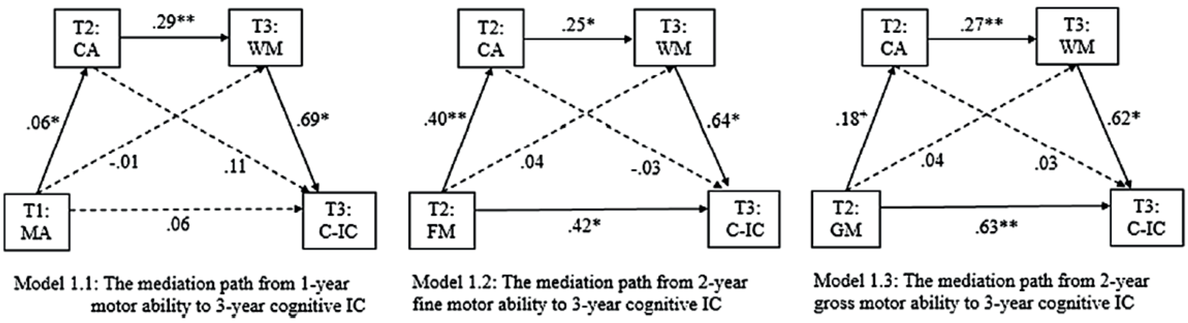

Figure 3. *Mediation analyses from infant motor abilities at age 1 (MA), fine and gross motor skills at age 2 (FM/GM) to cognitive inhibition control (C-IC, age 3) via cognitive ability (CA, age 2) and working memory (WM, age 3) (from Wu et al., 2017).*

Models that examined the path from motor ability to working memory via cognitive ability and cognitive inhibition control revealed no significant paths.
These results support the assumption of an effect from infant motor skills on later EFs.

At preschool age EFs have also been found to be associated with motor skills (Cameron et al., 2012; Livesey et al., 2006). For example, in a study by Cameron et al. (2012), fine motor skills correlated with an EFs inhibition task (r = .15) in three-to-four-year-olds. In a study with adolescents, overall motor skills accounted for a significant proportion of the variance in visuospatial working memory and inhibition, while gross motor skills accounted for unique variance in both verbal and visuospatial working memory (Rigoli, Piek, Kane, & Oosterlaan, 2012). Further support comes from a neuroimaging study, which found that infant motor performance was linked with EFs in adults (Ridler et al., 2006).

Overall, evidence has accumulated for an association between motor skills and basic and higher cognitive functions. On one side, EFs enable high-demand motor and cognitive tasks; on the other side, motor skills and basic cognitive functions are assumed to be a basis for the development of EFs. However, no final explanation has been provided so far for interrelatedness. An additional point that should be investigated in further studies is the environment of the children. Following the sociocultural theory and corresponding study results about cognitive development , it is obvious that the social context in which the child grows up affects the development of basic cognitive functions and EFs (Bernier, Carlson, Deschenes, & Matte-Gagne, 2012; Bjorklund, 2005e; Hughes & Devine, 2017).

3.3.3 Central themes in child development

The investigation of motor and cognitive skills and EFs is structured by the central themes of child development (Kail, 2004b). The most central themes in the research field of child development are generally focused around the following three questions: (1) How well is early development related to later development? This question examines the stability and predictability of development. To which extent do the abilities or behavior of a young child predict the child's later abilities and behavior? (2) Is development connected across different domains? It is assumed that various developmental domains are interrelated and interdependent (Diamond, 2007); thus, advances in one domain can lead to advances in another domain. To reveal these connections would be of great benefit to our understanding of developmental courses. (3) How do biology and environment influence development? Which factors influence development, which of them are modifiable, and which not? Whereas early theories believed in either the influence of biology or environment, today it is known that both aspects have an impact on development and interact. We want to understand in greater detail which factors are at play in children's development to know where to apply prevention (Kail, 2004b).

3.3.4 Aims of this thesis

The aims of the current thesis were to extend knowledge about the stability and predictability of motor and cognitive skills in preschool age, to examine the association of these two skills and EFs, and to identify predictors of EFs. In addition, the assessment of motor skills by parental reports was examined as a practical benefit. The four articles addressing these aims are described below.

1) **Stability and predictability of motor skills and cognitive skills in preschoolers**

   Motor skills and cognitive skills are important factors in child development and are assumed to be interrelated to some extent. Information about the stability and predictive value of motor and cognitive skills is important, especially at preschool age, when pediatric well-child visits take place, to make prognoses on further development and initiate therapeutic intervention if needed. Stable developmental domains make screening examinations for developmental disabilities more reliable than instable domains. Both domains are considered stable traits during development from school age through adolescence.

However, knowledge about stability during preschool age is scarce. Moreover, there is evidence that motor skills predict later cognitive outcome, rather than vice versa. To address the question of stability and predictability in preschool age, we examined the intra-individual stability and cross-wide association between motor and cognitive skills using a latent variable cross-lagged panel model.

Article: Zysset, A. E., Kakebeeke, T. H., Messerli-Bürgy, N., Meyer, A. H., Stülb, K., Leeger-Aschmann, C. S., Schmutz, Einat A., Arhab, A., Kriemler, S., Munsch, S., Puder, J. J., Jenni, O. G. Stability and prediction of motor performance and cognitive functioning in preschoolers: a latent variable approach, *submitted*

2) **Connection of motor and cognitive inhibition in preschoolers**

Inhibitory control is assumed to be an early component of EFs that forms the foundation for higher cognitive skills and may develop during the period from infancy to preschool (Best, 2010; Garon et al., 2008). The intensity of associated movements is considered a measure of the immaturity of the motor system (Mayston, Harrison, & Stephens, 1999), and inhibitory control is linked to the child's cognitive processes (Diamond, 2013). To date, it is not known to what extent motor inhibition and cognitive inhibitory control are related. We hypothesized that these inhibitory processes may have a common basis in the immaturity of the prefrontal cortex, which may cause increased associated movements and limited cognitive inhibitory control. We investigated the association of motor inhibition (associated movements), cognitive inhibition (self-regulation and selective attention), working memory (EF component), and general cognitive skills in typically developing preschool children.

Article: Kakebeeke, T. H., Messerli-Burgy, N., Meyer, A. H., Zysset, A. E., Stülb, K., Leeger-Aschmann, C. S., Schmutz, E. A., Arhab, A., Puder, J. J., Kriemler, S., Munsch, S. Jenni, O. G. (2017). Contralateral Associated Movements Correlate with Inhibitory Control and Selective and Visual Attention in Preschool Children. *Perceptual and Motor Skills, 0*(0), 1-15.

3) **Which factors influence the development of executive functions in preschoolers**

Findings from previous studies indicate that the association between motor skills and cognitive skills might result from shared control processes of EFs, which drive performance in higher-demand tasks of both domains. In addition, EFs represent a crucial factor in children's development, because they are associated with academic achievement, social interactions, and attentional deficit. Optimal development in children would be supported by the identification of predictors of EFs. We addressed the question of biology and environment by investigating the effect of individual and interpersonal predictors on EFs. Individual demographical/biological factors were sex, age, SES, preterm birth, body fat, motor skills, and physical activity. Individual psychological factors were child characteristics, social interaction, cognitive functioning, and EFs at baseline. Interpersonal factors were parenting style, parenting stress, presence of siblings, amount of time spent outdoors, and days spent in a child care center. We selected variables based on previous research, following the approach of a socio-ecological model. Based on this analysis, we aimed to identify the most crucial factors for EFs that might be indicative for promoting EFs.

Article: Zysset, A. E., Kakebeeke, T. H., Messerli-Bürgy, N., Meyer, A. H., Stülb, K., Leeger-Aschmann, C. S., Schmutz, Einat A., Arhab, A., Kriemler, S., Munsch, S., Puder, J. J., Jenni, O. G. Predictors of Executive Functions in Preschoolers: Findings from the SPLASHY study, *submitted*

4) **Practical implementation: Association of parental report on motor skills and a standardized motor test in preschool age**

Because motor skills might predict cognitive functions, and to avoid the negative consequences of atypical or delayed motor skills in daily and social activities, it is important to assess motor performance early. This allows therapeutic intervention and support for the child to be introduced where needed. Aiming to improve the identification of delayed or atypical motor development, we examined the suitability of a parental report on motor skills. Pediatric practice would benefit from knowing whether questions about the daily motor activities of a child correlate with motor skills measured by a standardized test. Although evidence exists that parents provide valid and reliable reports about early motor milestones during the first years of life (Bodnarchuk & Eaton, 2004; Libertus & Landa, 2013; Majnemer & Rosenblatt, 1994), we do not know whether fundamental motor skills reported by parents during the preschool years ultimately reflect the child's performance in a standardized motor test. Thus, we constructed a six-item questionnaire of fundamental motor skills based on questions frequently asked in pediatric practice (Baumann & Pellaud, 2011; Jenni & Largo, 2014) and compared the answers with objectively measured fundamental motor skills.

Article: Zysset, A. E., Kakebeeke, T. H., Messerli-Bürgy, N., Meyer, A. H., Stülb, K., Leeger-Aschmann, C. S., Schmutz, Einat A., Arhab, A., Ferrazzini, V., Kriemler, S., Munsch, S., Puder, J. J., Jenni, O. G. (2018). The validity of parental reports on motor skills performance level in preschool children: a comparison with a standardized motor test. *European Journal of Pediatrics*.

4

Research articles

4.1 Stability and prediction of motor performance and cognitive functioning in preschoolers: a latent variable approach

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Abstract

At preschool age, motor skills and cognitive functions are regularly examined at well-child visits. Although reliable screening depends on the stability of the assessed developmental domains, not much is known about stability of motor and cognitive performance in preschool age. The aim of the present study was to investigate how stable motor skills and cognitive functioning are in preschool age and whether they can predict their own and respective outcome one year later. Examined were 509 children (46.4% female; *M* = 3.9 yrs.; *SD* = 0.6; range 3.0 – 6.0 yrs.) from the Swiss Preschoolers' Health Study (SPLASHY) at baseline and one year later. Latent Variable Cross-lagged Panel Model revealed that both motor skills and cognitive functioning are highly stable in the preschool age (.70/.69). Significant predictive value was found for motor skills on cognitive outcome (.37), but not vice versa. We conclude that cognitive functioning and motor skills are highly stable already in the preschool years and that motor skills can predict cognition. Future intervention studies should test the effect of encouragement of motor skills on cognitive development in early childhood.

Introduction

There is a continuous scientific interest in the association between motor skills and cognitive functioning during childhood. Many studies suggest that mutual interactions exist between these two domains (Davis et al., 2011; Diamond, 2000; Jenni et al., 2013; Roebers & Kauer, 2009). The idea of a close connection between motor skills and cognition was already postulated by Jean Piaget (Piaget, 1952). In his theory of cognitive development in children, he hypothesized that exploring the environment physically is needed for reaching higher levels of cognitive functions, or figuratively speaking 'understanding by grasping'.

Empirical studies on the relationship between motor performance and cognition have given rather inconsistent results (Michel et al., 2011b; Niederer et al., 2011; Roebers & Kauer, 2009; Seitz et al., 2006; Smits-Engelsman & Hill, 2012; Wassenberg et al., 2005). On the one hand the connection between these two abilities is supported by clinical studies (e.g., preterm children, (Seitz et al., 2006)) and from neuroimaging studies (Desmond, Gabrieli, Wagner, Ginier, & Glover, 1997; Diamond, 2000). According to Diamond (2000), the longstanding assumption that the prefrontal cortex is primarily linked to cognitive functions and the cerebellum to motor performance is not tenable. Investigations with brain damaged patients and observations of children with developmental disorders reported that the dorsolateral prefrontal cortex and the neocerebellum are often co-activated during motor and cognitive tasks (Awh et al., 1996; Fiez et al., 1996; Piek, Pitcher, & Hay, 1999; Schlosser et al., 1998).

In contrast, several studies with healthy, normally developing school-age children, found no general relation between motor and cognitive performance (Ahnert et al., 2003; Jenni et al., 2013; Roebers & Kauer, 2009; Wassenberg et al., 2005). Yet, weak to strong positive correlations between specific aspects of the two domains were observed in school age children and adolescents. For instance different aspects of motor skills correlated with visual processing and visuo-spatial working memory (Davis et al., 2011; Wassenberg et al., 2005). An overview of these correlations is provided in the review by Van der Fels et al. (2015). In sum, the more complex motor and cognitive tasks are, the more strongly they are correlated, supporting the hypothesis of common underlying processes. Several authors postulated that these overlapping processes may be attributed to executive functions (Livesey et al., 2006; Roebers & Kauer, 2009; Wassenberg et al., 2005). Executive functions are control processes which regulate cognition and behavior (Miyake & Friedman, 2012) and are needed in any task involving high demand, such as in new or complex tasks, tasks with changing conditions, time constraints or emphasis on accuracy (Hughes & Graham, 2002). Thus, while there seem to be overlapping processes between underlying categories, which are active when performing motor and cognitive tasks (Davis et al., 2011; Jenni et al., 2013), a direct relationship between them rather does not occur.

The long-term stability and association between motor skills and cognitive functioning is of great interest, because the prediction of motor skills and cognitive functioning on later outcomes is of essential practical relevance in the field of child health. Both domains are considered as stable traits during the development from school age through adolescence. Stable development – more precisely intra-individual stability – means here that the level of performance remains the same from child- until adulthood. Information about stability is important, especially in the preschool age, when well-child visits take place. Stable developmental domains make screening examinations for developmental disabilities more reliable then instable domains. However, most studies were focusing on school-age children, while evidence in the preschool age about the stability and predictive value of motor and cognition is scarce. An exception is the study of Piek et al. (2008) examining the predictive value of motor und cognitive skills in a small sample of 33 children from birth to 4 years on later outcomes in school age. They found that early gross motor skills predicted cognition outcome, while early fine motor skills did not predict either fine motor skills or cognition. Roebers et al. (2014) found high stability of fine motor skills (.75) in 169 5-6-year-old children. Furthermore, fine motor skills were weakly predictive of IQ one year later (20). In this study, IQ was found to be less stable (.26), but executive functions were as stable as motor skills (.75). Ahnert and Schneider (2007) examining 152 children from 4 to 23 years of age reported a large variability of stability coefficients (.31 – .69) depending on the domain and the time interval. Overall, motor skills were found to be moderately stable from childhood through early adulthood in this study. Another longitudinal study by Jenni et al. (2011) reported weak to moderate stability of motor skills (.46 - .61) and high stability for IQ (.72) in 6 to 18 year old children. In sum, stability coefficients range from moderate to high in motor skills and cognitive functioning, while some evidence for a predictive value of motor skills on late outcomes is reported. We note, however, that different age groups, methods and instruments make a comparison between studies challenging.

To address the question of an association between the motor and cognitive domain in a rather unstudied group of young children, we focused on 3-5-year-old typically developing preschool children and added information about stability and prediction between the domains. Therefore, the same standardized test instruments with good psychometric properties were used longitudinally over one year in a latent variable approach. Our specific aim was to examine whether motor and cognitive performance are stable in preschool age and can predict their outcome one year later.

Methods

Overview

The data presented in this paper are drawn from the Swiss Preschoolers' Health Study (SPLASHY) (ISRCTN41045021), which is a multi-site, prospective cohort study including

555 children healthy children at preschool age within two sociocultural areas of Switzerland (German- and French-speaking). In the first wave 476 children were tested and in the second wave 382 from the first wave (20% drop out) with additional 79 new children were tested. The average time period between the two waves was 1.0 year. The sample of 79 children being assessed in 2015 for the first time was slightly younger (0.23 years based on mean) than the sample of the 476 children measured in 2014 for the first time. Therefore the 79 new children were added to the first wave and their scores for the second wave imputed. Children were recruited from 84 child care centers in five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, and Zurich). These cantons together made up 50% of the Swiss population in 2013. Recruitment lasted from January 2013 until October 2014. The detailed study design and the overall objectives have been described in a methodological paper (Messerli-Burgy et al., 2016). The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee) and is in accordance with the Declaration of Helsinki. Parents provided written informed consent.

Participants

For the current analyses 509 children (46.4% female) were included. Mean age of the sample was 3.9 years (*SD* = 0.6, range: 3.0 – 6.0 years). Our sample consisted of typically developing children from the general population. The mean socioeconomic status of the family was 62 (*SD* = 16, range: 17 – 89) (Ganzeboom, 2010). Medical conditions were assessed through a parental questionnaire: 41 children were preterm born (33 week 37-32, 5 week 31-29, and 3 week 28 or earlier), 1 child suffered from Attention-Deficit/Hyperactivity Disorder and no one reported Autism or developmental delay. Exclusion criteria were kept to a minimum to obtain a large external validity, for this reason all aforementioned children with medical conditions were included.

Procedure

Subjects were tested in their own child care centers on three afternoons. The first afternoon included assessments of motor performance and the second afternoon focused on cognitive functioning, while the third afternoon focused on stress reactivity, which is not part of the current analysis. Each child was tested individually. All examiners were trained and quality checks were performed periodically, based on videos recordings. The motor test took 15-20 min and was recorded on digital video. Scoring of the videos took place offline. Scorers were trained and supervised by senior scientists of the Child Development Center. The cognitive test took 30 min and was scored during the test situation.

Measures

Cognitive functioning. Cognitive functioning was measured using four subtests of the Intelligence and Development Scales – Preschool (IDS-P; (Grob, Reimann, Gut, & Frischknecht, 2013)). The full test battery is used to determine the state of cognitive development, psychomotor abilities, social-emotional competency, mathematic skills, speech performance and motivation. Advantages of the IDS-P are an easy application, the appropriate age range for our study and the Swiss based norm population. The IDS-P has a standardized procedure and analysis, shows high internal consistency for cognition ($\alpha = .91$) and high retest-reliability after 5 months ($r = .90$). Criterion validity is given through comparisons with other frequently used cognitive tests (German versions of K-ABC and WISC-IV). Furthermore, the IDS-P has a high construct validity for age trends and shows good intercorrelation with individual scales and factor loading (Grob et al., 2013; Hagmann-von Arx, Petermann, & Grob, 2013).

We used four cognitive subtests of the IDS-P (one of each cognitive component: perception, attention, memory, and reasoning). Only four instead of all seven tasks were used due the time restriction in our study schedule. These four subtests showed an internal consistency in our sample of $\alpha = .51$.

Visual perception: The child had to sort eight times five cards with colored pencils according to different sizes of the pencils on each card. The cards had to be laid down horizontally on a template that showed a small tree on the left and a big tree on the right side. The instruction was to put the smallest pencil under the small tree and order the other pencils according to size so that the biggest pencil was positioned under the big tree. The difference between the pencils became smaller with each sub-item of the task (10 mm – 0.5 mm). Scoring: For each card put in the right position one point was given. Per sub-item a maximal score of five points was possible. For all eight sub-items a total score of 40 points could be reached.

Selective attention: The child had to sort cards showing ducks with yellow or white beaks. On some cards there was additionally a yellow sun, which had to be ignored. The task was to make two piles as quickly as possible separating cards showing ducks with yellow from ducks with white beaks. Within 90 seconds as many cards as possible had to be sorted. Scoring: Amount of total sorted cards minus incorrect sorted cards. A total score of 72 points could be reached.

Visuo-spatial working memory: The child had to remember colored geometric figures and recognize them afterwards in a template with other figures. The relevant cue was the geometric shape while the color had to be ignored as it changed in the template. The amount of items to remember increased from one to four during the task. For remembering all figures one point was given. A half point was given for remembering the majority of the figures and zero points were given for not remembering or remembering the wrong figures. A total score of 10 points could be reached.

Figural reasoning: The child had to recreate geometric figures with 3D bricks. The instructor created a geometric figure – consisting of triangles and rectangles – in front of the child. The figure remained visible, while the child was recreating the figure. Scoring: 1 = Correct figure and 0 = wrong figure. The figure was rated as wrong when the differences between the bricks were more than 5mm and/or the position of the figure differ more than 45° from the template figure. The tasks consisted of 12 sub-items and a total score of 12 points could be reached.

During all cognitive tasks the child was sitting on a chair at a table. The order of the tasks was always the same, and the tasks were stopped when the child had three wrong items in a row.

Motor performance. Motor performance was assessed using the Zurich Neuromotor Assessment 3-5 (ZNA 3-5; (Kakebeeke et al., 2013; Kakebeeke, Caflisch, Locatelli, Rousson, & Jenni, 2012)). The ZNA 3–5 is based on the original ZNA for children older than five years (ZNA 5–18; (Largo, Rousson, Caflisch, & Jenni, 2007b; Largo et al., 2001a; Largo et al., 2001b)) and is a well-standardized motor test instrument. The ZNA 3-5 has a high intra-observer (k_w = 0.56-1.00) and inter-observer (k_w = 0.42-0.99) reliability, while test-retest reliability is lower in some tasks (0.35-0.84) (Kakebeeke et al., 2013). We used a shortened version of the ZNA 3-5 in this study, again due to time restriction. The performed tasks are listed hereafter.

Handedness was determined by letting the child perform three unimanual tasks: drawing a line with a pencil, cutting paper with a scissors, putting a peg into the instructor’s hand. The hand used for most of the tasks was called dominant hand, the leg on the same side was also called dominant. Testing was always started with the dominant hand and leg.

Component pegboard. A board with 12 holes was placed in front of the child sitting at a table. 14 plastic pegs were laid in a small plate beside the pegboard. All holes had to be filled out with pegs with one hand. First, the dominant hand was tested, then the non-dominant. The inactive hand was placed in a relaxed position beside the pegboard in a hollow. The pegs were transferred to either side of the board for the dominant or the non-dominant hand. The pegs were picked up in any order, but only one at a time. No transfer of a peg from one hand to the other was allowed. The time assessment started when the child picked up the first peg and stopped when the child released the last peg. The task was first demonstrated by the instructor. No practice trials were given.

Component pure motor. Pure motor tasks measure motor abilities which are considered as genetically determined and therefore less changeable by practice and experience (Burton & Miller, 1998; Jenni et al., 2011). Children were positioned on a chair in front of the examiner, and were instructed to place their legs into a position where hip, knee, and ankle joints are flexed at a 90° angle. For each task, the examiner made verbal instructions while demonstrating the demanded performance. The examiner continued the performance during the child's performance. The time to perform the required number of movements for the dominant and the non-dominant side was recorded for the following tasks:

1. Repetitive hand movements: 10 pats of one hand with the wrists resting on the thighs and the palm of the inactive hand held down.

2. Alternating hand movements: 5 pairs of alternating movements of one hand with the wrists resting on the thighs and the palm of the inactive hand held up.

3. Repetitive finger movements: 10 taps between index finger and thumb while arms held up sideways, shoulders at a 90° angle abduction and elbows at a 90° angle flexion.

Component static balance. Standing on one leg: The examiner gave the instruction "Stand on your right/left leg as long as you can." Timing started when the child lifted one foot off the floor and stopped when the child touched the floor with the lifted foot, or shifted the foot of the standing leg more than 2 cm, or when the time limit of 30 seconds was reached. The same procedure was repeated for the other foot. A qualitative score was given from 0 to 4: 0 = Can stand on both legs more than 5 seconds; 1 = Can stand on only one leg more than 5 seconds; 2 = Can stand on both legs between 2 and 5 seconds; 3 = Can stand on only one leg between 2 and 5 seconds; 4 = Not able to stand on either leg for more than 2 seconds.

Component gross motor. Dynamic balance is an adaptive motor skill that depends on multiple abilities such as muscle strength, endurance, and gross body coordination and also receives input from sensory, perceptual, and cognitive processes (Jenni et al., 2011). An elastic cord was placed on the floor between two chairs located four meters apart from each other.

1. Walking on a straight line: The instruction was to walk on the cord by putting one foot in front of the other. The heel of the anterior foot had to touch the toes of the foot behind. A qualitative score was given from 0 to 4: 0 = Perfect performance, heel touching toes; 1 = Distance between the two feet, feet straight; 2 = Feet not straight and/or misses the line 1-3 times; 3 = Feet perpendicular and/or does not touch the line > 3 times; 4 = Not able to walk with both feet on the line.

2. Hopping on one leg: The child was asked to hop as many times as possible on one leg, next to the elastic cord. The task was done for each leg, and two trials for each leg were given. A qualitative score was given from 0 to 4: 0 = Can hop on both legs more than 7 times; 1 = Can hop on only one leg more than 3 times; 2= Can hop on both legs from 1 to 3 times; 3 = Can hop on only one leg from 1 to 3 times; 4 = Cannot hop on either leg.

3. Side-to-side jumping: The child was asked to stand beside the cord and to jump forth and back over the cord sideways while keeping the feet together. A qualitative score was given from 0 to 4: 0 = Perfect performance, very smooth jumping; 1 = Jumping is correct but not very smooth; 2 = Touchdown with two feet at the same time, jumping very stiff; 3 = Total body

involvement, poor coordination in relation to the line direction; 4 = Jumping about but not in relation to the line.

4. Running: the child had to run 20 meters around the two chairs (5 x 4 meter). A qualitative score was given form 0 to 4: 0 = Rolling motion of feet with adjustment of upper body; 1 = Rolling motion of feet, stiff upper body; 2 = Running with partial rolling motion of feet; 3 = Running without any rolling motion of feet; 4 = Cannot run (no flight phase).

Statistical Analyses

Statistical analyses were performed using SPSS (IBM, SPSS; Version 23.0, Chicago, IL, USA), and R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were calculated by means ± standard deviations for continuous variables and frequencies and percentages for categorical variables. Descriptive statistics of the included measures are shown in Table . To investigate the longitudinal association between motor skills and cognitive functioning a structural equation model was created whereby cognitive functioning and motor skills for both time points (t1 and t2) were represented through latent constructs. Our structural equation model has been referred to as latent variable cross-lagged panel model (Newsom, 2015). All four latent constructs were first verified as separate measurement models with confirmatory factor analysis (CFA). The CFA and latent variable cross-lagged panel model were performed in R with the package lavaan (latent variable analysis). The model's fit was assessed as good when the standardized root mean square (SRMR) was smaller or equal 0.8, root mean square error of approximation (RMSEA) was smaller or equal .06, p value of RMSEA >.05, comparative fit index (CFI) was greater than .90 (Lei & Wu, 2007). Chi-square testing is very sensitive to sample size, therefore we considered the normalized chi-square test, which indicate a good fit < 2 (Schreiber, Nora, Stage, Barlow, & King, 2006). Full information maximum likelihood method was used to estimate missing values. Results were compared to an analysis including only cases with complete data (n=226, completer analysis) performed in R. Both motor and cognitive measures were standardized to receive identical metrics across tasks. All performance was expressed as standard deviation scores (SDS) calculated from age- and sex-adjusted normative values. Positive values corresponding to above average performance and negative values to below average performance. The statistical significance level alpha was set at 0.05.

Results

Descriptive measures of the raw values of the cognitive and motor tasks of both waves (t1 and t2) are presented in Table 1. Comparisons between the two waves demonstrated that children performed better in motor and cognitive tasks after one year ($p < 0.05$, paired t-tests or Wilcoxon signed-rank tests). In the cognitive tasks they scored higher after one year, while in motor tasks they became faster and received a better scale score. Correlations among all indicator variables are shown in Table 2. Most cognitive and motor tasks correlated weakly to moderately with each other. Furthermore, all performances from t1 are correlated significantly with the corresponding performance in t1 (e.g., fine motor skills in t1 correlates with fine motor skills in t2).

Table 1. *Descriptive statistics of the raw values of cognitive (IDS-P) and motor tasks (ZNA 3-5) for both measurement points (t1 and t2).*

			M (SD)	Range
Cognitive functioning[1]				
Perception	Visual perception	t1	17.6 (6.7)	5-36
		t2	24.0 (6.6)	6-40
Attention	Selective attention	t1	28.4 (10.8)	1-67
		t2	39.2 (12.1)	3-72
Memory	Visuo-spatial working memory	t1	3.8 (2.2)	0-9
		t2	5.3 (2.3)	1-10
Reasoning	Figural reasoning	t1	2.5 (2.3)	0-12
		t2	4.7 (3.1)	0-12
Motor performance[2]				
Fine motor	Pegboard (sec)	t1	51.4 (15.8)	21.4-137.0
		t2	38.3 (9.0)	21.8-92.1
Pure motor	Repetitive FM (sec)	t1	5.0 (1.1)	2.9-11.7
		t2	4.4 (1.0)	2.8-9.0
	Repetitive HM (sec)	t1	4.5 (1.0)	2.8-11.4
		t2	4.1 (0.8)	2.2-8.1
	Alternating HM (sec)	t1	6.8 (2.4)	3.1-19.3
		t2	5.2 (1.1)	2.8-8.8
Static balance	Standing on one leg (sec)	t1	8.4 (7.1)	2.1-64.8
		t2	12.2 (9.7)	2.3-77.7
Gross motor	Walking on straight line[3]	t1	2.1 (0.8)	0-4
		t2	1.8 (0.7)	0-4
	Side-to-side jumping[3]	t1	2.6 (1.0)	0-4
		t2	2.0 (1.1)	0-4
	Hopping on one leg[3]	t1	2.4 (1.4)	0-4
		t2	1.1 (1.2)	0-4
	Running[3]	t1	2.4 (0.8)	0-4
		t2	1.9 (0.6)	0-4

Note. [1] Values are based on passed items (see description of single tasks).[2] Values are means of right and left hand/leg performance. Repetitive FM = rep. finger movement, repetitive HM = rep. hand movement. [3] Values based on scale 4-0 (see description of single tasks). Differences between t1 and t2 were all significant (P<0.05, paired t-tests/Wilcoxon rank test).

The four measurement models (cognition t1/t2 and motor skills t1/t2) which were tested separately using CFA, each revealed a good model fit: Cognition t1 (X2 (2) = 2.13, p = .35, CFI = .999, RMSEA = .01, RMSEA Pclose = .68, SMRM = 0.14), cognition t2 (X2 (2) = 2.36, p = .31, CFI = .993, RMSEA = .02, RMSEA Pclose = .56, SRMR = .02), motor skills t1 (X2 (2) = 2.47, p = .29, CFI = .996, RMSEA = .02, RMSEA Pclose = .62, SRMR = .02) and motor skills t2 (X2 (2) = 1.41, p = .50, CFI = 1.00, RMSEA = .00, RMSEA Pclose = .71, SRMR = .01). The fit of the entire latent variable cross-lagged panel model was satisfactory (x^2 (90) = 169.73, $p < .001$, normalized $x^2 = 1.88$, CFI = .91, RMSEA = .04, RMSEA Pclose = .92, SRMR = .06). We did not conduct post-hoc modifications because indicated modifications did not correspond with our theoretical model.

Table 2**.** *Pearson Correlations between all included indicator variables.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Visual perception t1	-															
2. Selective attention t1	***.183***	-														
3. Working memory t1	***.237***	**.145**	-													
4. Figural reasoning t1	***.188***	***.198***	***.243***	-												
5. Fine motor t1	***.176***	***.259***	***.169***	***.175***	-											
6. Pure motor t1	**.109**	**.125**	**.111**	.001	***.196***	-										
7. Static balance t1	**.122**	**.124**	**.120**	.086	***.257***	***.221***	-									
8. Gross motor t1	**.155**	***.206***	**.102**	**.103**	***.187***	**.145**	***.338***	-								
9. Visual perception t2	***.244***	.061	.066	***.252***	.068	.074	**.139**	**.134**	-							
10. Selective attention t2	***.226***	***.384***	**.175**	**.157**	***.300***	**.179**	***.217***	**.117**	***.202***	-						
11. Working memory t2	**.182**	.033	***.258***	**.184**	**.179**	.024	**.155**	**.181**	***.213***	.095	-					
12. Figural reasoning t2	***.200***	***.267***	**.176**	***.367***	***.289***	.031	**.130**	**.179**	**.185**	***.193***	**.169**	-				
13. Fine motor t2	***.227***	**.181**	**.151**	**.168**	***.542***	**.164**	**.191**	***.212***	.084	***.416***	**.125**	***.257***	-			
14. Pure motor t2	.038	.067	-.105	-.042	-.072	***.241***	.038	.027	-.052	.101	**-.119**	-.096	.076	-		
15. Static balance t2	**.181**	***.261***	.043	.025	**.194**	**.123**	***.507***	***.318***	.105	***.213***	.048	**.114**	***.312***	.059	-	
16. Gross motor t2	**.191**	***.313***	**.113**	**.119**	***.284***	***.209***	***.354***	***.499***	.072	***.314***	.107	**.152**	***.327***	**.131**	***.453***	-

Note. Correlations in **bolt** are significant at $p < .05$; correlations in **bold** and *italics* are significant at $p < .001$

Results of the latent variable cross-lagged panel model are presented in Figure 1. Cognitive functioning and motor skills were significantly related at t1 (r = .65). Both cognitive functions and motor skills showed high stability over one year with autoregressive coefficients of .70 (*p* = .004) and .69 (*p* < .001), respectively. Cross-lagged coefficients in contrast were much smaller and only that between motor skills at t1 and cognitive functioning at t2 was significant (.37, *p* = .04), whereas that between cognitive functioning at t1 and motor skills at t2 was not (.21, *p* = .14). In the analysis including only cases with complete data (n = 226) coefficients were as follows: autoregressive coefficients were .74 (*p* < .01), for cognition and .82 (*p* < .001) for motor skills, cross-lagged coefficients were .33 (*p* = .09) between motor skills at t1 and cognition at t2, and .03 (*p* = .81) between cognition at t1 and motor skills at t2.

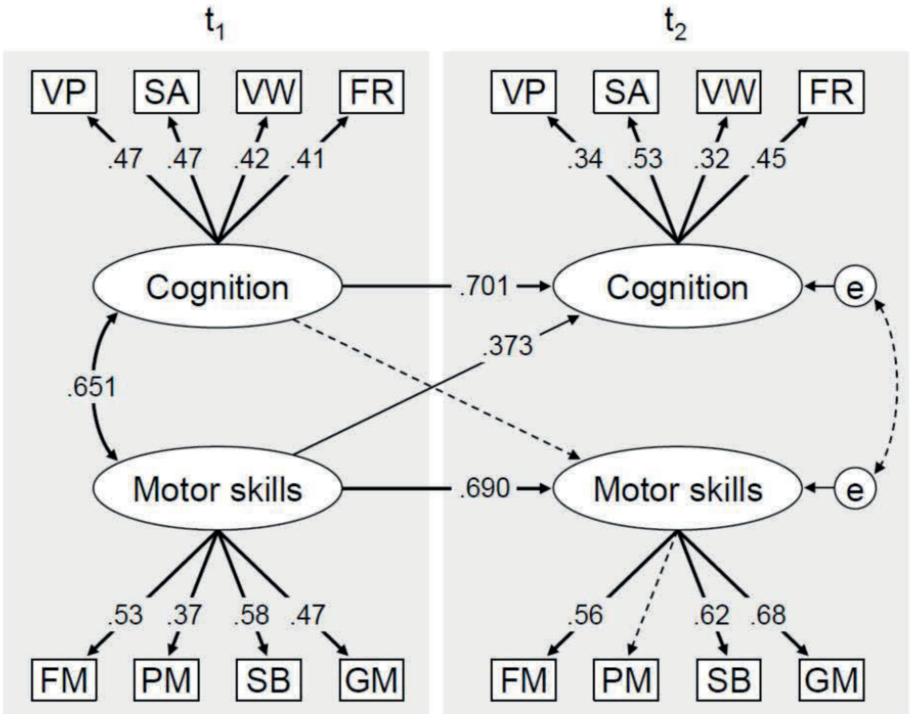

Figure 1. *Latent variable cross-lagged panel model examining the longitudinal (two measurement points t1 and t2) interrelation between motor skills and cognitive functioning. VP = Visual perception; SA = Selective attention; VM = Visuo-spatial working memory; FR= Figural reasoning; FM = Fine motor; PM = Pure motor; SB = Static balance; GM = Gross motor; e = error term. Bolt lines represents paths significant at p < .001; (path between cognition t1 and t2 p = .004); thin lines represent paths significant at p < .05; non-significant paths are presented in dashed lines. Correlations between residuals of the indicators are not shown for simplicity.*

Discussion

The aim of the present study was to examine the longitudinal association between motor skills and cognitive functioning in 3-5-year-old preschool children. With a time interval of one year, stability and predictive values were assessed using a latent variable cross-lagged panel model. Both cognitive functioning and motor skills were found to be highly stable over one year in 3-5-year-olds. It is known that both domains are linked via common underlying processes such as executive functions. For this reason, a cross-lagged relationship between characteristics of these two domains was expected. However, we only found a significant relationship for motor skills at t1 on cognitive functioning at t2 but not vice versa. This is in line with other studies that found predictive value of motor skills on cognitive outcome (Piek et al., 2008; Roebers et al., 2014)

Compared to previous studies (Ahnert & Schneider, 2007; Jenni et al., 2011), our stability coefficients were rather high. Ahnert and Schneider (2007) found higher stability values for motor skills in school age but not for preschool age. The authors argued that one reason could be the use of different test batteries in different age groups. Thus, one reason that our stability coefficients were quite high may partly be due to the method used. Firstly, we used instruments (IDS-P and ZNA3-5), which can be applied to a broad age range without changing items. Secondly, in latent variables, measurement errors are reduced because they are not aggregated in a residual error term and hence estimated coefficients increased (Lei & Wu, 2007).

As other authors discussed, it is difficult to compare stability coefficients tested across different time intervals, with varying age groups and with different methods (Ahnert & Schneider, 2007). Our results are best comparable to the study of Roebers et al. (2014) which as well used a latent variable approach and a time interval of one year, with children being one year older than the children in our study. Interestingly, they also found high stability for (fine) motor skills in 169 children between 5 and 6 years (.75) but a low stability for IQ. Our stability for cognition is more similar to their stability found for executive functioning (.75). A possible explanation for this might be that our measurement of cognition includes two tasks, selective attention and visuo-spatial working memory, both of which rely on executive functions (Garon et al., 2008).

Limitations of our study are that we have only two measurement points. This implies that our results mainly refer to the preschool age range but cannot be applied to school age or later. Still – regarding the young age of our children and the challenging test implementation in this age – the high stability of motor skills and cognitive functioning seems remarkable. Another weakness is the low internal consistency levels of cognition measures.

The key strength of this study is the large, representative sample of typically developing children including children as young as 3 years of age. Moreover, two sociocultural areas of Switzerland were considered (which are known to differ significantly in various health indicators (Leeger-Aschmann et al., 2016). The same standardized test instruments with good psychometric properties were used to examine motor performance and cognitive functioning longitudinally for the entire age range. We note that other studies often had to use several instruments for different age groups (Ahnert et al., 2003; Ahnert & Schneider, 2007).

Another strength is the used latent variable approach which allows to examine multiple regression paths between latent variables simultaneously (Lei & Wu, 2007). Furthermore, measurement errors, which tend to attenuate estimated relationships, can be removed due to the latent constructs. Internal consistency of our tasks was moderate, which is indicative of using latent variables instead of building sum scores.

The assessment of the stability of motor skills and cognitive functioning in the preschool years is important for clinical practice. At preschool age, children are regularly seen at well-child visits. Reliable screening depends on the stability of the examined developmental domains. Our study may indicate that motor and cognitive development are reliable domains for screening and, thus, reliable indicators for the identification of children at risk for delayed motor or cognitive development already at the age of 3 to 5 years.

Early identification of children at risk would enable an early intervention. Given the fact that motor skills and cognitive functions predict school achievement (Roebers et al., 2014), early interventions are desirable. Furthermore the significant cross-lagged relationship between motor skills at t1 and cognitive development at t2 is in line with Piaget's (1952) original idea and was observed in previous studies (Piek et al., 2008; Roebers et al., 2014). Thus, future intervention studies should test the effect of encouragement of motor skills on cognitive development in early childhood.

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4.2 Contralateral associated movements correlate with inhibitory control and selective and visual attention in preschool children

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Abstract

Contralateral associated movements (CAMs) frequently occur in complex motor tasks. We investigated whether and to what extent CAMs are associated with inhibitory control among preschool children in the Swiss Preschoolers' Health Study. Participants included 476 healthy, typically developing children (mean age = 3.88 years; 251 boys) and were evaluated on two consecutive afternoons. The children performed the Zurich Neuromotor Assessment, the statue subtest of the Neuropsychological Assessment for Children (NEPSY), and cognitive tests of the Intelligence and Development Scales-Preschool (IDS-P). CAMs were associated with poor inhibitory control on the statue test and poor selective attention and visual perception on the IDS-P. We attributed these findings to preschoolers' general immaturity of the central nervous system.

Introduction

Alongside the idea that typical motor development in children accompanies undisturbed cognitive, social, and emotional development, assessing early motor functioning has become increasingly important (Piek, 2006; Piek, Hands, & Licari, 2012). Motor development, described as expected changes in motor performance over time (Clark & Whitall, 1989), can be assessed through overt motor behavior. A general characteristic of motor development in children is increased ability to selectively activate muscles required for a specific movement while inhibiting activation of others not involved in the movement (Kottke, 1980; Kottke, Halpern, Easton, Ozel, & Burrill, 1978; Latash, Turvey, & Bernstein, 1999).

While experienced motor performers display smooth, efficient, and elegant movements (Latash et al., 1999) that result from the efficient inhibition of involuntary movements, younger, less-experienced performers typically show too much motor activation of extraneous movements present in body parts not actively involved in the task. These so-called contralateral associated movements (CAMs) are sometimes seen as mirror movements or motor overflow (Hoy et al., 2004). These additional extraneous movements may occur on the contralateral extremity of the intended or voluntary movement. For instance, during the performance of a one-hand task, the contralateral or opposite hand may show a parallel extraneous movement. This phenomenon is mostly seen in children below six years of age, as they try to perform one-handed motor tasks. A decrease of CAMs over the course of motor development has been described by several research groups (Connolly & Stratton, 1968; Hoy et al., 2004; Largo et al., 2001a; Licari & Larkin, 2008) and is explained by an increase in inhibition due to maturation of the prefrontal cortex (Huttenlocher & Dabholkar, 1997). This inhibition is the result of improved executive functions (EFs), defined as control mechanisms allowing a dynamic regulation of cognitive and behavioural processes (Miyake & Friedman, 2012).

Inhibitory control is a fundamental early component of EF (Best, 2010) that forms the foundation for higher cognitive functioning and may develop during the infancy to preschool period (Garon et al., 2008). Since inhibitory control involves withholding or restraining a motor response (Garon et al., 2008), it is expressed motorically. To date, it is not known to what extent CAMs are related to inhibitory control. We hypothesized that these inhibitory processes have a common basis in that immaturity of the prefrontal cortex may cause increased physical CAMs and limited psychological inhibitory control.

The intensity of CAMs is considered a measure of the immaturity of the motor system (Mayston et al., 1999), whereas inhibitory control is linked to the child's cognitive processes (Diamond, 2013). Because inhibitory control is dependent on maturational processes that differ between boys and girls and, on such other factors as social background, the socioeconomic status (SES) of the family, we included gender, and age as covariates (Piek, 2006). We sought to describe the relation between CAM intensity and inhibitory control in healthy children between two and six years of age.

Method

Participants

The Swiss Preschoolers' Health Study is a multisite prospective cohort study involving 476 preschool children (mean age 3.88 years; SD = 0.68; 251 males and 225 females) from two sociocultural regions of Switzerland (German and French speaking parts, registration number ISRCTN41045021). Childcare center selection was stratified according to urban and rural community and high and low SES. Of 639 childcare centers first contacted, 84 centers participated. Recruitment of the children took place via parents who were contacted by childcare educators. We only excluded children who clearly could not perform the tasks or whose health and treatment interfered with our testing. The detailed study design and overall objectives were described elsewhere (Messerli-Burgy et al., 2016). Children were recruited between November 2013 and October 2014 when all participants were two to six years old. The study was approved by all local ethical committees and was conducted in accordance with the Declaration of Helsinki. Parents provided written informed consent.

Procedure

Participants were tested within their childcare centers; their test performances were recorded on digital video. Children were tested individually by an experimenter on two different afternoons, and an educator from the childcare center was always present. The first afternoon included assessments of motor skills (Kakebeeke et al., 2013), and the second focused on assessment of cognitive skills and inhibitory control. Motor scores for data analyses were determined from video observations; cognitive scores were obtained through the test.

Assessments

CAMs measured with the Zurich Neuromotor Assessment. The Zurich Neuromotor Assessment (ZNA) is a standardized procedure for assessing the speed of several motor tasks (Kakebeeke et al., 2013; Kakebeeke et al., 2014; Largo et al., 2001b) and the quality of movements (intensity of CAMs; Largo et al., 2001a). For the ZNA3–5, for children between age 3 and 5, we used the same items as in the ZNA5–18 (Largo et al., 2001a), the original database for children between age five and 18, but adapted them for younger children (e.g., fewer repetitions; (Kakebeeke et al., 2013)). The ZNA3–5 was validated recently for 3-5-year-old children (Kakebeeke et al., 2016). An important aspect of the ZNA is that the children were always asked to move as quickly and as precisely as possible. The tasks were performed in the same order by all children. First, the child performed all adaptive motor tasks at a table. Then the child sat on a small chair for repetitive and alternating movements of the hand and fingers. The examiner explained verbally how to perform the tasks and then demonstrated them. If the child did not understand the task and did something different from what was demonstrated, demonstrations and explanations were repeated. If they failed again, the examiner scored the task as ‘‘failed’’ and continued with another item. Data for the timed performance are not presented in this article but elsewhere (Kakebeeke et al., 2017).

Handedness. Handedness was determined by asking the child to perform three unimanual tasks. The hand used for the majority of the tasks was considered the dominant hand.

Task 1: CAMs during adaptive motor tasks—pegboard with dominant and nondominant hand (AM1 and AM2). For the adaptive motor or pegboard task, the child sat at a table with the lower arm parallel to the table and the feet always on the floor, with hips, knees, and ankles at 900. The task was performed with both hands. For all timed tasks, the child was asked to complete the task as quickly as possible. One hand rested on the board, while the other hand placed 12 pegs into 12 holes. The examiner first demonstrated how to put a peg into a hole, but no practice was allowed. The stopwatch was started when the child touched the first peg and was stopped when the child released the last peg. The frequency or duration of CAMs was scored in 10th of the number of movements; the amplitude was scored on a 4-point scale: 0 = no movement, 1 = weak finger or hand movements (just visible), 2 = moderate finger or hand movements (clearly visible), 3 = marked finger or hand movements or movements analogous to the active hand (like in the active hand; Largo et al., 2001a). A new parameter, CAM intensity, was defined with the following formula ‘‘square root of the (CAM frequency x CAM amplitude - 0.5),’’ allowing all data to be distributed between 0 and 5 (Gasser & Rousson, 2004). Intrarater reliability values for CAM values range from 0.82 to 0.90, while interrater reliability CAM values are between 0.57 and 0.88 (Rousson, Gasser, Caflisch, & Largo, 2008).

Tasks2–5: CAMs during pure motor tasks: Repetitive and alternating movements of the hands and repetitive and sequential movements of the fingers with dominant and nondo- minant hand (AM3–AM10). Children performed these tasks sitting on a chair with hips, knees, and feet at a 90° angle, hands on the knees or held in the air, and abduction in the shoulder of 70 to 90°. The examiner gave verbal instructions while demonstrating the task. No practice trials were allowed. The following motor tasks with dominant and nondominant hands were performed during which the CAMs were scored: repetitive hand movements (AM3, AM4), alternating hand pro- and supination (AM5, AM6), repetitive finger movements (AM7, AM8), and sequential finger movements (AM9, AM10). The CAMs were scored in the same way as in the pegboard task.

Sum of tasks: CAMs 1 to 10. For the CAMs 1 to 8, the children had to perform a timed task during which the CAMs were measured. During the sequential movements of the fingers (AM9, AM10), timing proved not to be very useful, as about half of the children could not perform the task. A qualitative score was given of 0 (perfect), 1 (little movement), 2 (moderate movement), 3 (strong movement, as on the other side), and absent (movement was not possible for the working hand). For all tasks, the children were asked and stressed to perform the task as quickly and precisely as possible.

Inhibitory control. Inhibitory motor control was measured with the statue motor persistence subtest of the Neuropsychological Assessment for Children (NEPSY; Korkman, Kirk, & Kemp, 1998) . During the statue test, the child is asked to stand straight, with eyes closed, beside a chair, as if holding a flag with the right arm parallel to the legs. The child is further asked to suppress undesired or inappropriate movements (Becker, Miao, Duncan, & McClelland, 2014; Diamond, 2013; Lakes, 2013). As in a classical go/no go test, the statue test permits measurement of motor inhibitory control, thought to be part of executive system self-regulation (Donzella, Gunnar, Krueger, & Alwin, 2000). At this age, the statue test is an appropriate, age adapted, easy to administer behavioral test. We coded the video clips for undesired bodily movements and facial reactions, using experienced psychologists as raters. Interrater reliability achieved a = .99. During the test, the child is asked to maintain a set position as a ‘‘statue’’ and to avoid body movement, eye opening, or talking for a 75-second period while the examiner distracts the child with such several different noises as a pencil drop (at 10 seconds), a single cough (at 20 seconds), a double knock on a table (at 30 seconds), and a clearing of the throat (at 50 seconds). The task is videotaped, and the inhibition of impulse reactions to these distracters is coded at 5-second intervals. Motor persistence is measured as follows: Children with appropriate responses (no movement, no eye opening, and no vocalization) achieve a maximum of two points; for one single inappropriate response, they receive one point and they receive zero points for several inappropriate responses, with a maximum total of 30 points. This motor persistence test measures inhibitory control explicitly. The statue test shows high internal reliability of a = .79 to .81 for children aged three to six years (Brooks, Sherman, & Strauss, 2010).

Cognitive function. We measured cognitive functioning with the Intelligence and Development Scales–Preschool (IDS-P; Grob, Meyer, & Hagmann-von Arx, 2009; Grob et al., 2013). The full preschool version of the IDS-P (Grob et al., 2009; Grob et al., 2013) assesses general cognitive development through seven subtests divided over four different cognitive subcategories: perception, attention, memory, and reasoning. For each of these subcategories, we selected one subtest (visual perception, selective attention, visuospatial working memory, and figural reasoning, respectively) so as to cover all four categories within a reasonable time frame. The raw scores of each test were transformed into age- and gender-standardized values according to the IDS-P manual (Grob et al., 2013). The IDS-P has a high internal consistency for cognition (a = .91) and shows good intercorrelation with individual scales (Grob et al., 2013).

SES. SES was calculated by transforming coding of the occupational status of both parents into an International Socio-Economic Index (ISEI) value (Ganzeboom, 2010). The maximal SES was then determined by selecting the highest of the maternal and paternal ISEI values.

Child's health. We assessed the children's health through the parental version of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) consisting of 25 items assessing emotional symptoms and behavioral problems (including conduct problems, hyperactivity/inattention, and peer problems). Of the 25 attributes asked, 10 are considered strengths, 14 are difficulties, and one is neutral. We utilized the SDQ total score for data analysis. Reliability of SDQ in our sample was satisfactory (a = .71) but lower than the a = .82 of the test's normative sample of Woerner et al. (2002).

Statistical Analysis

To construct normative CAM values for motor skills, we considered dominant and nondominant sides of the body separately, treating age as a continuous covariate. We studied both the frequency and amplitude of CAMs, and as noted, we created and analyzed a new parameter, CAM intensity for each motor task. CAMs could only be measured when the child was able to perform the task; when a child was unable to perform a task, there were no CAMs. Since our study involved typically developing children, we were able to describe CAM intensity for every task as a z score (i.e., standard deviation [SD] scores, based on the mean for all participants); positive values corresponded to above-average and negative values corresponded to below-average performances. A summary of CAM scores for all tasks (AM1– AM10) was constructed for the ZNA by averaging z scores over all participants and all tasks, yielding one overall CAM intensity score per child. Of note, as there was no significantly different dominant and nondominant hand performance over all children, data for separate hands were pooled.

Statistical analyses were conducted using SPSS (IBM, SPSS; Version 23.0, Chicago, IL, USA). Descriptive statistics are presented using mean ± SD and minimum and maximum range for all continuous variables. Outcome variables were checked for normal distribution and homoscedasticity. Distribution of motor persistence was skewed and had to be square root transformed prior to any statistical analysis. To assess the association between CAMs and inhibitory control, a multilevel model was set up with child and childcare center representing Levels 1 and 2, respectively. The child's CAMs were the lower level predictor and inhibitory control the lower level outcome variables. The model contained a random intercept for childcare center. All analyses were adjusted by covariate analyses for age, gender, and family SES. In multilevel models, children with missing predictors or covariate values are excluded from the analysis, whereas cases with missing outcome values are kept in the model and estimated.

Results

Of the 476 children in this study, motor tasks of the ZNA could be analyzed in 377, and the NEPSY statue test could be analyzed in 396. In all other cases, either the child did not complete one of the two tests (due to absence on the testing day) or the video material was not valid, leading these cases to be excluded from analyses. The mean age of the sample was 3.98 years (SD = 0.70) and the mean family SES was 61.5 (SD = 16.1). The sample consisted of 191 boys and 186 girls. The descriptive findings of CAMs, inhibitory control (motor persistence), and the four cognitive tests are presented in Table 1. Parental judgment of the child's health was consistent with normal estimates in comparison with the literature (Woerner et al., 2002).

Associated Movements as a Predictor of Inhibitory Control

After controlling for age, gender, and SES, the multilevel model revealed a significant relationship between CAMs and motor persistence (p = .001), selective attention (p = .050), and visual perception (p = .001). However, there was no significant relationship between CAM intensity and the two IDS-P cognitive tasks of visuospatial working memory and figural reasoning (see Table 2).

Table 1. *Descriptive Statistics of the Sample.*

Parameter	Mean	*SD*	Min	Max
Age	3.98	0.69	2.69	6.64
Maternal socioeconomic status	58.55	16.17	17	89
Paternal socioeconomic status	56.62	17.44	17	89
Maximum socioeconomic status of family	61.51	16.05	17	89
Associated movements (all; CAMs)	−0.14	1.02	−3.24	2.96
Motor persistence (NEPSY statue test)	21.12	8.68	0	30
Selective attention (IDS-P)	9.28	2.79	2	19
Visual perception (IDS-P)	10.05	2.68	1	17
Visuospatial working memory (IDS-P)	9.31	3.19	1	18
Figural reasoning (IDS-P)	7.54	2.54	1	19
Emotional symptoms (SDQ)	1.68	1.59	0	9
Conduct problems (SDQ)	2.74	1.84	0	10
Hyperactivity/inattention (SDQ)	3.14	2.05	0	10
Peer problems (SDQ)	1.28	1.42	0	6
Total difficulties (SDQ)	8.84	4.4	0	25

Note. N = 377. CAMs = contralateral associated movements; NEPSY = Neuropsychological Assessment for Children; IDS-P = Intelligence and Development Scales; SDQ = Strengths and Difficulties Questionnaire.

Table 2. *Parameter Estimates From Linear Mixed Models for CAMs as a Predictor of Inhibitory Control (Represented by Motor Persistence) and Other Cognitive Functions (Selective Attention, Visual Perception, Visuospatial Working Memory, and Figural Reasoning).*

	Fixed coefficients		Random coefficients		Goodness of fit		
Outcomes	Coefficient	95% CI	Level-1 σ_E^2	Level-2 σ_0^2	ICC	AIC unconditional means model	AIC fitted model
Motor persistence	.363	[0.191, 0.535]***	2.047	0.036	.086	1,539.86	1,028.19
Selective attention	.329	[0.034, 0.623]*	6.211	0.185	.053	2,013.99	1,370.02
Visual perception	.597	[0.299, 0.894]***	6.225	0.294	.035	1,986.99	1,374.89
Visuospatial memory	.271	[−0.109, −0.652]	9.046	1.423	.052	2,013.99	1,489.44
Figural reasoning	−.067	[−0.363, −0.227]	5.573	0.741	.096	1,896.42	1,341.96

Note. CAMs = contralateral associated movements; CI = confidence interval. σ_E^2: estimated variance within childcare centers (between children). σ_0^2: estimated variance between child care centers. ICC: intraclass correlation coefficient based on conditional means model (i.e., without any predictor in the model). AIC: Akaike information criterion: goodness-of-fit measure, with lower values denoting better fit. ***p = .001. *p =.050.

Discussion

In this study, we found an association between CAM intensity and correlates of inhibitory control in children at preschool age. The more CAMs children displayed during the ZNA motor test, the more inhibitory control problems were observed during the NEPSY statue test, reflecting the child’s difficulty refraining from exhibiting motor reactions to irrelevant distracting stimuli. Additionally, we found a relation between the intensity of CAMs and the children’s performance on the selective attention and visual perception subtests of the cognitive functioning test (IDS-P), both of which are known to be related to overall EF. Children with a high intensity of CAMs reacted more to distracting stimuli than children who had few CAMs. The association between the intensity of CAMs and extraneous motor reactions on the NEPSY statue test was similar to the relation between CAM intensity and performance on the IDS-P selective attention task.

The investigation of inhibitory processes in child development is generally challenging, as it involves assessing brain functioning that is invisible to the human eye. For instance, although one can measure the time children need to pick up a candy bar, it is more difficult to measure how well they can suppress their urge to open the candy and eat it after having been forbidden to do so. Fortunately, we can observe whether children show CAMs during motor tests and note whether they show unwanted extraneous motor activity during the NEPSY statue test which essentially asks them to stand in one posture and make no movements. By relating these two measurements, the intensity of CAMs can be seen as a measure of more general motor network immaturity and, as such, as a measure for interhemispheric inhibition (Gaddis et al., 2015; Waber, Mann, & Merola, 1985). For preschool-aged children tested in this cohort, cortical maturation is incomplete (Paus et al., 1999; Yakovlev & Lecours, 1967), the inhibitory role of prefrontal cortex structures is not yet fulfilled. Since the intensity of CAMs decreases with age (Addamo, Farrow, Hoy, Bradshaw, & Georgiou-Karistianis, 2007; Connolly & Stratton, 1968; Largo et al., 2001a; Mayston et al., 1999), we can assume that cortical maturation is responsible for the change.

Cortical maturation is not only related to reduced CAM intensity but also to the inhibition of some startle responses involved, for example, in the NEPSY statue task in which children are asked to stand still and fail when they react to distracting stimuli with unintended reactive movements. These extraneous statue test movements are different from the CAMs during the ZNA in that movements in the NEPSY statue task can be seen as partly purposeful in the child’s reactions to distracting stimuli. Yet, as the results of these two tests are correlated, we might suppose that their commonality relates to immature cortical development.

A further illustration that cortical immaturity accounts for both is that some cognitive tasks are also associated with both CAMs and statue test difficulty. Specifically, we used the selective attention subtest of the IDS-P to determine how well our participants could focus on a certain task and ignore irrelevant environmental information (Garon et al., 2008), and we found a positive relation between CAM intensity and performance on the selective attention task. Again, children who had the highest CAM intensity also showed the greatest difficulty with selective attention. To date, only one other research group has published data on the relation between motor overflow and attentiveness to task-relevant and task-irrelevant cues (Waber et al., 1985), and this group found similar results in a sample of nonclinical school-aged children with many CAMs and high responsiveness to task-irrelevant cues.

Furthermore, we found an additional positive relationship between visual perception on the IDS-P and CAMs. On the visual perception subtest, the child had to sort cards showing similar objects according to their different sizes. We found a stronger relationship of CAMs to visual perception ($\beta = .597$) than to motor persistence problems on the statue test or to performance on the selective attention measure. The strong relation between visual perception performance and CAMs was not accompanied by significant associations between CAMs and visuospatial working memory and figural reasoning. One explanation could be that brain development is insufficiently advanced in preschool children for the relationship to be found on these more complex tasks involving memory and reasoning. Second, sorting cards according to their size was the most straightforward test and very suitable to the age of the children. In our opinion, the IDS-P tests of selective attention and visual perception revealed the strongest relationship with CAMs because they are most strongly related to the same age-associated brain maturation processes.

Neural development provides one explanation for the occurrence of CAMs and the lack of inhibitory control at that age that changes over time. Obviously, neuronal networks underlying inhibitory action mature and gain control with increasing age. Thus, relative immaturity is a basis for lack of inhibition in the nervous system, perhaps related in turn to physical immaturity (i.e., not yet myelinated) in brain structures (e.g., prefrontal cortex and corpus callosum), responsible for inhibition (Mayston et al., 1999). One common denominator of the outcomes of our three tests was a lack of inhibition and associated EF activity.

So far, the relationship between the intensity of CAMs and inhibitory control has been investigated in few studies of typically developing children between two and six years of age. Previous studies have focused on the effect of age and EF maturation. Addamo et al. (2007) found that motor overflow (in this article CAMs) was present in healthy children until about 10 years and in the elderly, and they offered mediation by the corpus callosum as a possible explanation. Inhibitory control and inhibition improves during early childhood (Best, 2010; Garon et al., 2008), and differences in inhibitory capacity have been detected in comparisons of preschool and school-aged children (Klenberg, Korkman, & Lahti-Nuuttila, 2001). We found significant relationships between CAMs, inhibitory control, and early cognitive tasks in healthy preschool aged children, but limited inhibition capacity might be clinically significant only after age six when better inhibitory control is expected and observable (Klenberg et al., 2001). Persisting CAMs have been reported in older children suffering from attention deficit hyperactivity disorder (ADHD; D'Agati, Casarelli, Pitzianti, & Pasini, 2010; Licari & Larkin, 2008; Mahone et al., 2011). Other authors showed that CAMs predict impaired inhibitory control in children with ADHD (Gaddis et al., 2015; Mostofsky et al., 2006). In line with these clinical studies, we found an association of CAMs and lack of inhibitory control in younger, healthy, typically developing children.

Clearly, further research is needed. Our findings are limited to the particular test measures utilized in this study, and future research might employ various related measures to cross-validate these findings. Additionally, longitudinal studies involving repeated measures of the same participants over development would elucidate the extent to which these factors are age-specific and demonstrate the presumed predictive value of CAMs for detecting problems with inhibitory control and such other early cognitive skills as selective attention and visual perception. With regard to clinical practice, future studies might demonstrate correlations between CAMs and symptoms of various neurodevelopmental disorders (e.g., ADHD, motor disorder, autism spectrum disorder) in younger and older children to help reveal the extent to which CAMs might assist early detection and be used to help evaluate intervention efficacy.

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4.3 Predictors of executive functions in preschoolers: Findings from the SPLASHY study

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Abstract

Executive functions have been reported to play a crucial role in children's development, affecting their academic achievement, health, and quality of life. This study examined individual and interpersonal predictors for executive functions in 555 typically developing preschool children aged two to six years. Children were recruited from 84 child care centers in the German- and French-speaking parts of Switzerland within the Swiss Preschoolers' Health Study (SPLASHY). A total of 21 potential predictors were assessed at the first measurement (T1). These included nine demographic/biological predictors, such as socioeconomic status, preterm birth, physical activity, and motor skills; six psychological predictors, such as hyperactivity, cognitive functioning, and emotionality; and six interpersonal predictors, such as parenting style and stress, presence of siblings, and days spent in the child care center. The predictive value of these variables on executive functions one year later (T2) was assessed using both standard multiple regression analysis and penalized regression to avoid overfitting due to the number of potential predictors. Sex ($\beta = .14$), socio-economic status ($\beta = .14$), fine motor skills ($\beta = .17$), cognitive functions at T1 ($\beta = .15$), and executive functions at T1 ($\beta = .30$) were all associated with executive functions at T2, exhibiting small to medium effect sizes. All predictors together accounted for 36% of the variability in executive functions. However, none of the interpersonal predictors were significant. Thus, we conclude that most of factors that can predict executive functions in preschool age are individual variables, and these tend to be more difficult to influence than interpersonal factors. In fact, children from families with low socio-economic status may be particularly vulnerable to poor executive functions. Furthermore, encouraging fine motor skills and cognitive functioning early in life may support the development of executive functions.

Introduction

Executive functions (EFs) are control processes which regulate cognition and behavior (Miyake & Friedman, 2012). They enable goal-directed behavior, thus, they are particularly needed in situations, which involve planning and decision-making, and inhibition of inappropriate behavior. Several studies investigating the functional structure of EFs have identified three main components: inhibition, working memory, and cognitive flexibility (Garon et al., 2008; Miyake et al., 2000). The neural mechanisms that regulate executive processes are primarily located in the frontal cortex, and they develop with maturation of the individual (Diamond, 2013; Garon et al., 2008; Miyake et al., 2000). A central time window for the development of EFs is the first five years of life, because the main components develop in this period and lay the foundation for later EFs (Garon et al., 2008).

EFs have attracted increasing attention, because numerous associations have been found to many aspects of life from infancy through adulthood (e.g., see overview in (Diamond, 2013)): For instance, EFs in preschoolers have been shown to predict early academic performance (Cameron et al., 2012; Mulder et al., 2017; Roebers et al., 2014). Strong EFs in preschoolers have also been linked positively to later outcomes such as social interactions, job success, and marital harmony and negatively to externalizing behavioral problems, attentional deficit, and substance abuse (Bailey, 2007; Eakin et al., 2004; Miyake & Friedman, 2012; Sawyer et al., 2015; Young et al., 2009).

The widespread associations of EFs all demonstrate EFs' importance. They also indicate the need to support EF development to facilitate the best possible academic achievement, health, and quality of life. Encouraging the development of EFs requires the identification of reliable predictors of EFs. Efforts can then be focused on those that can be trained or changed. Despite evidence that EFs are largely heritable (Engelhardt, Briley, Mann, Harden, & Tucker-Drob, 2015), some authors have reported factors such as positive parenting and physical activity as influencing EFs (Best, 2010; Hughes & Devine, 2017). Further influences have been assumed, but the cross-sectional design of previous studies did not allow causality to be confirmed. Hence, longitudinal studies are needed to clarify the causal direction of any such factors on EFs in early childhood. Following the approach of a socio-ecological model (Bauman et al., 2012; Bronfenbrenner 1995 in Kail, 2004b), the subsequent sections present a range of variables that previous studies have associated with EFs or found to predict later EFs. The sections deal in turn with individual demographic, biological, and psychological factors. They then deal with interpersonal factors such as parenting style, parenting stress, and the presence of siblings.

Individual demographic and biological factors

A study by Klenberg et al. (2001) reported that performance in EF tasks increases with age. Furthermore, these authors found that inhibition and impulse control mature earlier in girls than in boys. Children from families with higher socioeconomic status (SES) were found to perform better in EF tasks than children with low SES (Klenberg et al., 2001; Lawson, Duda, Avants, Wu, & Farah, 2013; Noble, Norman, & Farah, 2005). Noble et al. (2005) quantified the relationship between SES and EFs and reported that SES accounted for 15.3% of the variance in EF performance. Specifically, the educational level of parents explained most of this variance; no additional significant variance was explained by present occupation (score on the 7-point Hollingshead Occupation Status Scale) or family income (income-to-needs ratio). Furthermore, several studies have shown that preterm birth has an influence on EFs (Aarnoudse-Moens, Duivenvoorden, Weisglas-Kuperus, Van Goudoever, & Oosterlaan, 2012; Hagmann-von Arx et al., 2014; Wehrle et al., 2016). For instance, Wehrle et al. (2016) found that adolescents who were born very preterm (≤ 32 week) performed significantly lower in working memory, planning, and cognitive flexibility tasks compared to term-born children.

Two additional individual biological factors are motor skills and physical activity. EFs have repeatedly been found to be associated with motor skills (Cameron et al., 2012; Gottwald et al., 2016; Livesey et al., 2006). For example, Gottwald et al. (2016) postulated that EFs are ‘grounded in an infant’s developing ability to control and plan motor actions’ (p.1601). These authors indeed found that better prospective motor control (measured as velocity of reaching for an object) in 18-month-olds was positively correlated cross-sectionally with better inhibition and working memory (r = .31 – .39). A study by Cameron et al. (2012) found that fine motor skills correlated with the head-toes-knee-shoulders EF task (r = .15) in three-to-four-year-olds. In contrast, no association was found between planning in motor tasks and EFs in 3-to-10-year-old children in a study by Wunsch, Pfister, Henning, Aschersleben, and Weigelt (2016). One reason for this negative finding might be that the study used small groups (nine groups with on average 24 children), and planning skills were measured rather than motor skills per se. In a longitudinal study by Roebers et al. (2014), fine motor skills predicted only cognitive functioning, but not EFs, in school-age children. Overall, there is strong evidence for an association between motor skills and EFs from cross-sectional studies, but the predictive value of motor skills on EFs is unclear.

Lastly, cumulative evidence exists that regular physical activity contributes positively to cognitive functioning and EFs (Best, 2010; Chaddock et al., 2012; Dishman et al., 2006; Hillman & Schott, 2013; Monti, Hillman, & Cohen, 2012; Niederer et al., 2011). Three mechanisms by which physical activity might influence cognitive skills are assumed: “1. increase in oxygen saturation based on an increased blood flow and angiogenesis, 2. increase in brain neurotransmitters like serotonin and norepinephrine facilitating information processing and 3. regulation of neurotrophins such as different growth factors.” (Ploughman, 2008 in Niederer et al., 2011, p. 2). It has been found that physical activity has a direct effect on the brain structures that are related to cognitive and executive processes (Chaddock et al., 2010; Chaddock et al., 2012).

Individual psychological factors

A review article by Moriguchi (2014) suggested that social interactions might influence the development of EFs. There is evidence that better performance in EFs is associated with fewer behavioral problems, such as attention deficit disorder, hyperactivity, and conduct disorder (Hughes & Ensor, 2008; Miyake & Friedman, 2012; Young et al., 2009), thus, to clarify the causal direction longitudinal studies are necessary.

Another individual factor influencing the development of EFs is basic cognitive functions. However, it is not always easy to distinguish cognitive functions from EFs. To our knowledge, no definition has yet been agreed of the distinction between these two groups of functions. EFs are widely viewed as higher-order cognitive processes that are based on basic cognitive skills. Therefore, basic cognitive skills are related to EFs but do not account for the whole EF construct. The difference between cognitive skills and EFs becomes evident when comparing studies that have found a relation with only one of the two constructs. For example, motor skills predicted only cognitive functioning but not EFs in a study by Hughes and Devine (2017), while parenting influenced EFs but not cognitive functioning in another (Roebers et al., 2014).

Interpersonal factors

Siblings may promote children's development of EFs. It is hypothesized that a child may observe and imitate EF skills by playing games with rules (e.g., "wait until it is your turn"), negotiation, and learning strategic games with siblings and thus learn such skills faster. Another factor may be that siblings react more negatively and directly to inappropriate behavior (e.g., not following the game rules) than parents and other adults (Cole & Mitchell, 2000). McAlister and Peterson (2006) studied the relationship between EFs, siblings, and theory of mind development. They found that the presence of at least one child-aged sibling in the household was associated with better performance in EFs but not with theory of mind performance. Thus, the presence of siblings might be associated with and even promote EFs.

Evidence is accumulating that parenting style also has an effect on EFs. A study by Hughes and Devine (2017) showed that adverse parenting (negative affect, criticism, control) is negatively associated ($\beta = -.23$) with EFs. In contrast, positive parenting (scaffolding/supporting) showed a positive association (β = .19). However, neither parenting style showed a significant association with basic cognitive ability (measured with object assembling). In this 13-month longitudinal study by Hughes and Devine (2017) with 117 three-to-four-year-old children, neither the EFs of parents nor their education showed any effect on children's EFs. Another study by Blair, Raver, Berry, and Family Life Project (2014) found that higher parental sensitivity and responsiveness at the age of three years was associated with higher child EFs at age of five years. In contrast, another study found no association between EFs and parenting behavior; this study (Röthlisberger, Neuenschwander, Michel, & Roebers, 2010) measured the quantity of time that parents spent engaging with physical and learning activities, playing games, and talking with their child. Thus, qualitative aspects of the relationship between parents and children, such as being supportive and responsive seem mainly to have an effect on EFs rather than simple quantity of time. The supportive behavior of teachers can also have a positive effect on EF performance, especially when the parent-child relationship is conflictual (Vandenbroucke, Spilt, Verschueren, & Baeyens, 2017). Accordingly, institutions such as child care centers may be beneficial for the development of EFs, both through supporting relationships with child care educators and through social interactions with same-age children, which are likely to encourage following rules and appropriate behavior similarly to interaction with siblings.

In sum, many studies have been conducted on EFs, and a diverse range of associations have been identified. However, little evidence for factors predicting EFs is available from longitudinal studies. Furthermore, most studies have focused on only one predictor, not a comprehensive set of potential predictors, rendering direct comparison of magnitudes of influence on EFs infeasible. Finally, studies in young children are still scarce compared to studies involving school-age children and adolescents.

The aim of the present study was to examine potential predictors of EFs in typically developing preschoolers, including demographic, biological, psychological, and interpersonal variables. In contrast to previous studies, we investigated possible indicators from all domains affecting EFs. We selected variables used in previous research, following the approach of a socio-ecological model . Based on this analysis, we aimed to identify the factors most crucial to promoting EFs. We used a model of penalized regression that allowed variable selection and avoided overfitting due to the number of predictors tested simultaneously.

Material and Methods

Participants

Data were drawn from the Swiss Preschoolers' Health Study (SPLASHY, ISRCTN41045021), which is a multi-site, prospective cohort study of healthy children at preschool age. The sample for the current analysis thus consisted of 555 children (52.8% boys) between two and six years of age at their first measurement (mean = 3.9, SD = 0.7). Children were recruited from 84 child care centers in five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, and Zurich). These cantons together comprised 50% of the Swiss population in 2013. Recruitment of child care centers was stratified in four levels: urban and rural communities with high SES (above-average) and low SES (below-average), each based on the prevalence of child care centers in the communities. The detailed study design and overall objectives have been described in a methodological paper (Messerli-Burgy et al., 2016).

A total of 476 children participated in the first baseline assessment in 2014. In the follow-up assessment one year later, 382 of these children participated again (20% dropped - out), and 79 new children were tested for baseline (total 555 children). The same study team conducted data collection at baseline and follow-up in parallel at all study sites. While children recruited in 2014 (n=476) could participate in the follow-up assessment, those recruited in 2015 (n=79) underwent only baseline assessment. Baseline (T1) and follow-up (T2) data are used in this study. The study was approved by all local ethical committees (No 338/13 for the Ethical

Committee of the Canton of Vaud as the main ethical committee) and is in accordance with the Declaration of Helsinki. Parents provided written informed consent, and children provided oral consent.

Procedure

Subjects were tested in their own child care centers on three afternoons: on the first afternoon, a motor test was performed, and body composition was measured; on the second afternoon, self-regulation and executive and cognitive functioning was assessed; and on the third afternoon, a stress reaction test was executed. This last was not included in the current analysis. Each child was tested individually. All examiners were trained, and quality checks were performed periodically. In addition to the testing afternoons, each child wore an accelerometer for an entire week. Parents completed a questionnaire on general health (including anamneses of the child, demographical and environmental information of the family) and a questionnaires on psychological well-being (including characteristics of the child and parenting style). All questionnaires could be completed online or on paper.

Measures

Predictors (T1)

Nine demographic and biological variables were included. Information about *sex, age, prematurity* (< 37 weeks: yes/no), and *SES* were drawn from the general health questionnaire, which was constructed for the study by the research team. Sex was coded as zero for male and one for female. The SES of the family was calculated by coding the occupational status of both parents and transforming this into an International Socio-Economic Index (ISEI-08) value (Ganzeboom, 2010). Scores for this index can range from 16 for an unskilled worker to 90 for a judge. The maximal SES was then determined by the selection of the highest of the parental ISEI values. *Body fat* was measured by skinfold thickness of the triceps, biceps, subscapular, and suprailiac crest using standard procedures (Lohman, Roche, & Martorell, 1988). The sum of all four skinfolds was calculated. *Motor skills* included fine motor skills, pure motor skills, and associated movements; these were assessed using the Zurich Neuromotor Assessment 3-5 (ZNA 3-5; (Kakebeeke et al., 2013; Kakebeeke et al., 2012). Associated movements are involuntary movements that accompany the voluntary movement of a motor task and are assumed to indicate immaturity of the motor system. *Physical activity* was recorded objectively using a hip-worn accelerometer that measured tri-axial acceleration (wGT3X-BT, ActiGraph, Pensacola, FL, USA) for seven consecutive days. Accelerometer data was sampled at a frequency of 30 Hz, downloaded in three-second epochs, aggregated to 15-second epochs, and expressed as accelerometry counts per min averaged over the recording time and as time spent at various activity intensities. For this analysis, we used only physical activity spent in moderate to vigorous intensity. Cut-points were based on findings by Pate, Almeida, McIver, Pfeiffer, and Dowda (2006) for moderate to vigorous intensity (≥420 counts per 15s).

Six psychological, cognitive and emotional variables were included. *Hyperactivity, problems with peers,* and *prosocial behavior* of the child were rated online by the parents using the parental version of the Strength and Difficulties Questionnaire (SDQ; (Goodman, 2001)). The subscales achieved reliability scores of α = .69 (hyperactivity/inattention), α = .49 (peer problems), and α = .66 (prosocial behavior). *Emotionality (*α = .71) was also rated online by the parents using the Emotionality Activity Sociability Temperament Survey (EAS; (Buss & Plomin, 1984)) . *Cognitive functioning* was assessed with a visual perception task (IDS-P; (Grob et al., 2013). The goal of the tasks was to order cards that showed pencils of different sizes among the size of the pencils, from the smallest to the biggest. This sensory discrimination ability task has been found to correlate highly with general intelligence (r = .78 - .96) (Meyer, Hagmann-von Arx, Lemola, & Grob, 2010; Spearman, 1904). *EFs at T1* were included in the predictor list, measured analogously to EFs (T2) by calculating a mean of selective attention, self-regulation, and visuo-spatial working memory (see description of outcome measures).

Six interpersonal variables were included. *Parenting stress* was gathered online by a self-report using the Parental Stress Scale (PSS; (Berry & Jones, 1995)). Internal consistency in our sample was $\alpha = .80$. *Parenting style* was collected online by the Alabama Parenting Questionnaire (APQ; (Reichle & Franiek, 2009). This analysis included the subscales *positive parenting* and *inconsistent parenting*, which exhibited internal consistencies of $\alpha = .74$ and $\alpha = .71$ respectively. In the general health questionnaire, we asked whether at least one *sibling* (≤ 18 years) of the child lived in the household. Information was collected about the *time that the child spent outdoors* (min/day), and number of days that the child visited the *child care center* (half days/week).

All variables were z-standardized to provide the same units of measurement for the analysis.

Outcome: Executive functioning (T2)

Selective attention, from the Intelligence and Development Scales – Preschool (IDS-P; (Grob et al., 2013) is the child version of the d2-attention-endurance test (Brickenkamp, 1994). The task requires selective attention, inhibition, and speed of processing to achieve good results. The task can be used to measure the inhibition component of EFs. The child had to sort cards showing ducks with yellow or white beaks. The goal of the task is to separate the cards into two piles, one of each type of card, as quickly as possible. Some cards also showed a yellow sun, which the child had to ignore. As many cards as possible had to be sorted within 90 seconds. The task was scored immediately during the test. The score for each child was calculated as the total number of sorted cards minus the number of incorrectly sorted cards. A maximum score of 72 points was possible.

Self-regulation was measured with the statue subtest of the Neuropsychological Assessment for Children (NEPSY; (Korkman et al., 1998)). The statue test is an indicator of motor inhibition and resistance to interference from distractors. The task can be used to measure the inhibition component of EFs. The child was asked to maintain the position of a statue holding a flag with closed eyes for 75 seconds. The child was instructed to avoid moving, opening eyes, or speaking until the experimenter finished the test. During the test, the experimenter made several noises intended to distract the child. The task was videotaped, and the clips were coded by experienced psychologists for movements of body parts and facial reactions. Interrater reliability achieved $\alpha = .99$. Children with no movement, no eye opening, and no vocalization achieve a maximum of two points per 5-second interval; for a single inappropriate response, they received one point, and they received zero points for several inappropriate responses. A total of 30 points was possible.

Visuo-spatial working memory (IDS-P; (Grob et al., 2013)) requires focusing on and remembering of geometric form while ignoring color. The task can be used to measure the working memory/updating component of EFs. The child was instructed to remember colored geometric figures, presented on a page, and recognize them afterwards on a new page with other geometric figures. The relevant cue was the geometric shape; the color had to be ignored. The number of items to remember increased from one to four during the task. One point was given for remembering all figures. A half-point was given for remembering some of the figures (e.g., two out of three), and zero points were given for not remembering or remembering the wrong figures. A total score of 10 points was possible.

The outcome EFs (T2) were calculated as a mean of all three tasks described above. All scores for these tasks were transformed into standard deviation scores (SDS) and adjusted for age, with positive values corresponding to above-average performance and negative values to below-average performance.

Statistical Analyses

Statistical analyses were performed using R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria), including the R packages *glmnet* and *caret* for the lasso model (Friedman, Hastie, & Tibshirani, 2010; Kuhn et al., 2016) and *mice* for multiple imputation (Van Buuren & Groothuis-Oudshoorn, 2011). Descriptive statistics were calculated by means ± standard deviations for continuous variables and percentages for categorical variables (Table 1). To investigate the relationship between predictors at T1 and EFs at T2, we applied two different regression models. We first used a multiple regression model, which included the entire list of predictors to be tested (Table 1). Because multiple regression models regularly suffer from overfitting, leading to models with low predictive accuracy, we also used a variable selection procedure, the least absolute shrinkage and selection operator (lasso), as a second model (Hastie, Tibshirani, & Friedman, 2009).

In the lasso model, coefficients are shrunk by implying a penalty term to the estimated sum of squares of the residuals when fitting the model (Hastie et al., 2009). Therefore, lasso models are slightly more biased than multiple regression models, but they often show strongly increased predictive accuracy. Hence, predictors whose coefficients from penalized regression have not been shrunk to zero are more likely to be predictive when replicating the study. Simply put, the lasso technique removes unimportant predictors from the model by setting their coefficients to zero while the more relevant correlate variables remain. All variables were standardized prior to analysis for the lasso model. Since no tests of significance are available for the lasso method, no p-values are reported.

Multicollinearity was tested among the predictors involved in the analysis but presented no issue here (variance inflation factors ranging from 1.06 – 1.38). The data contained missing values; see Table 1 for data available for each predictor. Missing values were substituted using multiple imputation techniques. Prior to any analysis, missing values were repeatedly (i.e., fifty times) imputed using chained equations as implemented in the *mice* R package (Van Buuren &

Groothuis-Oudshoorn, 2011). Each imputation creates a different dataset in which estimated values replace missing values. Regression models were run fifty times using each of the complete datasets, and results were then pooled across the fifty datasets. To our knowledge, no technique yet exists to combine lasso-based results from several data files. Therefore, we determined the importance of each potential predictor by calculating the mean and standard deviation of each lasso coefficient across all fifty data files. Finally, mean standardized lasso coefficients are presented.

To facilitate comparison of results, we focus on the multiple regression model and add the lasso results as auxiliary. As supplementary material, we present results of single regression models for each predictor, using the original dataset containing only observed data. We mention the main concordances and discordances between the multiple regression model, the lasso model, and single regression models in the text.

Results

Descriptive statistics of predictors to be tested are shown in Table 1, which contains mean and standard deviation or percentage, range, and the number of children with data available for each variable. Results of the multiple regression model are presented in Table 2. In this analysis, all predictors together accounted for 36% of the variability in EFs at T2. As coefficients can be interpreted analogously to correlation coefficients (0.1 small, 0.3 moderate and > 0.5 large; (Cohen, 1992)), the effect sizes were all between small and medium. The largest effect size was found for EFs T1, (β = 0.30). Other significant predictors were sex (β = 0.14), SES (β = 0.14), and fine motor skills (β = 0.17) and cognitive functioning, (β = 0.15).

Table 3 contains the shrunk coefficients resulting from the lasso model. The cross-validated lasso model accounted for 32% of the variability in EFs, while the cross-validated standard multiple regression model accounted for 31% of the variability. Compared to the significant predictors in the multiple regression model (Table 2), the coefficients in the lasso were only slightly shrunk (3–14%), suggesting that the multiple regression model was only slightly overfitted. Compared to the non-significant predictors in the multiple regression model, the lasso coefficients were generally more shrunk (0–100%) and often set to zero.

Table 1. *Descriptive statistics of predictors tested.*

	n	*M or %*	*SD*	*Range*
Individual factors				
Demographic and biological variables				
Sex (% boys)	555	52.8	-	1/2
Age (years)	555	3.9	(0.7)	2.2-6.6
SES (ISEI score)	520	62.9	15.5	17-89
Born preterm (% yes)	516	7.6	-	0/1
Body fat (mm)[1]	495	26.0	5.5	14.6-51.0
Fine motor skills (SDS)	495	0.1	1.0	-3.1-3.4
Pure motor (SDS)	461	0.1	1.2	-4.6-3.8
Associated movements (SDS)	429	-0.1	1.0	-3.3-3.0
Moderate to vigorous PA (min/day)	505	92.0	29.7	25.9-206.5
Psychological variables				
Hyperactivity/Inattention[2]	510	3.2	2.0	0-10
Peer Problems[2]	511	1.2	1.4	0-6
Prosocial Behavior[2]	511	7.7	1.7	2-10
Emotionality temperament[3]	511	2.8	0.7	1-5
Cognitive performance (SDS)	513	0.0	1.0	-2.7-2.5
EFs (T1, SDS)[4]	449	0.0	0.7	-2.2-1.6
Interpersonal factors				
Parenting stress[5]	511	37.4	7.4	20-68
Positive parenting[6]	511	4.5	0.4	3.0-5.0
Inconsistent parenting[6]	511	2.5	0.5	1.0-4.2
Siblings (% yes)	552	67.8	-	0/1
Time outdoors (min/day)	507	144.1	87.5	0.0-480.0
Half days in childcare	548	5.5	2.6	0-10

Note: Where no unit of measurement is indicated, scores refer to the corresponding questionnaire scale. [1] body fat is the sum of 4 skinfolds; [2] Strength and Difficulties Questionnaire; [3] Emotionality Activity Sociability Temperament Survey; [4] EFs T1 is the mean of selective attention, self-regulation and visuo-spatial working memory at T1; [5] Parental Stress Scale; [6]Alabama Parenting Questionnaire.

Table 2. *Tested predictors of executive functions. Coefficients are based on multiple regression model.*

Predictors	β	95 % CI	p-value
Individual factors			
Demographic and biological variables			
Sex[1]	0.14	0.04, 0.23	.00
Age	- 0.03	-0.13, 0.07	.57
SES	0.14	0.05, 0.24	.00
Born preterm	- 0.05	-0.15, 0.05	.33
Body fat	- 0.05	-0.14, 0.04	.29
Fine motor skills	0.17	0.06, 0.28	.00
Pure motor	0.08	-0.04, 0.19	.19
Associated movements	0.00	-0.11, 0.11	.98
Moderate to vigorous PA	0.04	-0.05, 0.13	.35
Psychological variables			
Hyperactivity/Inattention	- 0.07	-0.16, 0.03	.15
Peer Problems	0.06	-0.04, 0.15	.24
Prosocial Behavior	- 0.04	-0.13, 0.05	.40
Emotionality temperament	0.01	-0.08, 0.10	.82
Cognitive performance	0.15	0.05, 0.26	.00
EFs (T1)	0.30	0.19, 0.41	.00
Interpersonal factors			
Family			
Parenting stress	- 0.01	-0.10, 0.09	.88
Positive parenting	0.01	-0.08, 0.10	.83
Inconsistent parenting	0.01	-0.07, 0.10	.77
Siblings	0.01	-0.08, 0.09	.84
Time outdoors	0.04	-0.04, 0.12	.33
Half days in childcare	- 0.06	-0.16, 0.04	.25

Note: All variables were standardized. [1] coded 0 = male/1=female.

Table 3. *Tested predictors of executive functions. Coefficients are shrunken and based on a lasso model.*

Predictors	mean (β)
Individual factors	
Demographic and biological variables	
Sex	0.12
Age	- 0.03
SES	0.12
Born preterm	- 0.03
Body fat	- 0.02
Fine motor skills	0.16
Pure motor	0.05
Associated movements	0.01
Moderate to vigorous PA	0.01
Psychological variables	
Hyperactivity/Inattention	- 0.04
Peer Problems	0.02
Prosocial Behavior	- 0.01
Emotionality temperament	0.00
Cognitive performance	0.13
EFs (T1)	0.29
Interpersonal factors	
Family	
Parenting stress	0.00
Positive parenting	0.00
Inconsistent parenting	0.00
Siblings	0.00
Time outdoors	0.02
Half days in childcare	- 0.05

Note: For the lasso method, no tests of significance are available yet, so no p-values are reported.

The results of the univariate regression models testing one predictor at a time without multiple imputation are shown in the supplementary Table 4. The comparison between Tables 2, 3, and 4 reveals the benefits of our methodological approach. While univariate regression analyses support our prior results, it also reveals additional significant predictors, which disappear in the lasso model, and thus, are not likely to be predictive.

Supplementary Table 4. *Single regression analyses of tested predictors of executive functions.*

	β	adjusted R^2	p-value
Individual factors			
Demographic and biological variables			
Sex	0.18	0.03	.00
Age	- 0.04	- 0.00	.43
SES	0.23	0.05	.00
Born preterm	- 0.13	0.01	.04
Body fat	- 0.03	- 0.00	.63
Fine motor skills	0.37	0.13	.00
Pure motor	0.16	0.02	.01
Associated movements	0.17	0.03	.00
Moderate to vigorous PA	0.03	- 0.00	.63
Psychological variables			
Hyperactivity/Inattention	- 0.15	0.02	.01
Peer Problems	0.02	- 0.00	.75
Prosocial Behavior	0.01	- 0.00	.90
Emotionality temperament	0.02	- 0.00	.71
Cognitive performance	0.31	0.09	.00
EFs (T1)	0.45	0.20	.00
Interpersonal factors			
Family			
Parenting stress	0.08	0.00	.14
Positive parenting	- 0.03	- 0.00	.63
Inconsistent parenting	0.04	- 0.00	.42
Siblings	0.09	0.01	.10
Time outdoors	0.06	0.00	.25
Half days in childcare	- 0.14	0.02	.01

Discussion

The aim of this study was to identify possible predictors of EFs in preschool-age children. We selected a broad spectrum of individual demographic, biological, and interpersonal factors from previous published evidence, measured these in a cohort of preschool children, and analyzed their predictive value on EFs one year later. The results show that the factors that significantly predicted EFs are all individual ones. We found that female sex, higher SES, better fine motor skills, better cognitive functioning, and better EFs at the first measurement were all predictors of higher EFs one year later. Interpersonal factors, such as parenting style, parenting stress, the presence of siblings, or amount of days that the child visited a child care center, did not predict EFs.

Our results showed that female sex and SES, despite small effect sizes, were among the most important determinants of EFs. Sex predicting EFs is in line with previous studies in preschoolers that found an association between sex and EFs, with girls outperforming boys (Klenberg et al., 2001). The plausible explanation is that girls mature earlier (Lim, Han, Uhlhaas, & Kaiser, 2015) and therefore EF development is more advanced in girls. Lim et al. (2015) found that the neuronal reorganization that makes information processing more efficient occurs earlier in girls than in boys.

Furthermore, we found that SES predicted EFs. Previous studies had already shown an association between SES and EFs. For example, in the cross-sectional study by Noble et al. (2005), SES was associated with EFs with a moderately large effect size. Although in our study SES predicted EFs with only a small effect size, our result supports the role of SES in EF development. The mechanism underlying this association is not yet fully understood. However, it has been noted that SES involves more than the variability in occupation, income, and education, which are the characteristics by which it is defined (Noble et al., 2005). Such factors as home environment, childhood experience, stimulation in childhood, health care access, early life stress, and neighborhood conditions are closely linked with SES and influence the development of children (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; Lupien, McEwen, Gunnar, & Heim, 2009; Moriguchi, 2014; Noble et al., 2005). Another essential link has been reported between SES, language skills, and EFs; In one previous study, SES and language skills both predicted EFs, but, SES explained no additional variance in EFs when language skills were controlled for (Noble et al., 2005). In fact, language skills might play a role in EF development via the self-regulatory function of language. For instance, language skills are needed in several EF tasks, and working memory performance depends on strategies that often involve verbal rehearsal (Hughes & Graham, 2002). No language skills where assessed in this study, so the causality path hypothesized here cannot be tested. However, perhaps SES and its related factors primarily influence the language skills that then drive EF performance.

Contrary to expectations and to previous findings (Aarnoudse-Moens et al., 2012; Hagmann-von Arx et al., 2014; Wehrle et al., 2016), being born preterm was not significant in predicting EFs. The predictor variable preterm born revealed a negative association with EF performance in the single regression analysis, but the effect disappeared in the multiple regression model and the lasso model. The reason of no effect might be that, although 8% in our sample were born preterm (≤ 37 weeks), few children (1.4%) were born very preterm (< 32 weeks). Due to the low number of preterm-born children, we decided not to split them into even smaller groups, but the mingling of preterm-born and very preterm-born children and the generally low sample size of preterm-born might be the reason for the absence of a significant predictive effect. Alternatively, preterm birth may have no predictive value after controlling for all the predictors included in the current study.

In line with previous results, fine motor skills predicted EFs. However, pure motor skills and associated movement showed no predictive effect. Pure motor skills are largely independent of experience and reflect motor speed. Associated movements are involuntary movements caused by failure of motor inhibition in the contralateral body side during motor tasks; these can be interpreted as indicators of the degree of maturation of the motor system. Hence, motor speed and motor inhibition seem not to predict EFs. In contrast, fine motor skills predicted EFs with a small effect size in both the multiple regression and the lasso model and thus can be assumed to be a reliable predictor of EFs.

The last biological predictor to be examined was moderate to vigorous physical activity. Although positive effects of physical activity on EFs and cognitive functions in general have repeatedly been reported (Chaddock et al., 2012; Hillman & Schott, 2013), no effect was found in this study. Best (2010) reported that physical activity that involves greater cognitive engagement in particular leads to increased EFs. He also proposed that 'EF may be more sensitive to aerobic exercise at one developmental time point than at another, and one EF component may be more sensitive to acute aerobic exercise than another' (Best, 2010, p. 6). Thus, in two-to-six-year olds, when EFs are developing, an effect of physical activity might not yet be ascertainable. We coded the amount and intensity level of physical activity, but not what the children were actually doing at each stage. Moreover, the children in our sample met the recommended guidelines for physical activity (min. 180 min/day total physical activity and min. 60 min/day moderate to vigorous physical activity; (Leeger-Aschmann et al., 2016)). Thus, we had a generally physically active and healthy sample. These factors might explain why no effect of physical activity could be found in our sample.

Child characteristics and temperament did not predict EFs. Hyperactivity was not predictive in the main analysis, but in the single analysis hyperactivity accounted for 2% variability in EFs. It is assumed that EFs and hyperactivity/inattention are linked, since lack of inhibition is likely to lead to hyperactivity and inattention. However, these two characteristics may influence test performance; being unable to focus and concentrate on the tasks, the child might score lower on EF tasks. This interaction should be kept in mind when testing EFs. Again, no effect was observed in our sample. Prosocial behavior was hypothesized to have a positive influence on EFs through training of inhibition skills, but no effect was apparent. Thus, child temperament and characteristics did not predict EFs. Our sample exhibited low scores for hyperactivity, peer problems, and emotionality and high scores on prosocial behavior. Of the psychological variables that were examined, only cognitive performance and EFs at the first measurement predicted EFs one year later. EFs at the first measurement predicted EFs one year later with only a moderate effect size, indicating that EFs might not be very stable at this age. The effect size of cognitive functioning is somewhat lower than the effect size of EFs, which shows that cognitive functioning is an essential part of future EFs and has an effect independent of baseline EFs but does not account for the whole EF performance.

Unexpectedly, we found no effect of parenting on EFs. Previous studies have provided evidence that quality of parenting does influence EFs (Blair et al., 2014; Hughes & Devine, 2017; Vandenbroucke et al., 2017), but we found no effect of parenting stress, positive parenting, or inconsistent parenting. In the lasso model, all these coefficients shrank to zero, indicating a very low probability that parenting factors influence EFs. Once again, this may be because parents in our sample did not report high levels of parenting stress (37.4) or negative parenting (2.5) and showed a normal level of positive parenting (4.5). All scores corresponded to the norm population (norm of parenting stress: 37.18; (Stadelmann, Perren, Kölch, Groeben, & Schmid, 2010) ; norm inconsistent parenting: 2.47; norm positive parenting: 4.25 (Reichle & Franiek, 2009)). Parenting variables are based on self-reporting, which can be biased by social desirability. However, previously reported parenting effects have generally been small. While an association between parenting and SES may exist (as discussed above), SES was more important than parenting style for predicting EFs in our study.

No effect was found for attending a child care center. We hypothesized that more days at the child care center would provide the child with greater benefit from social interaction with same-age children, positive support from child care educators, and promoted physical activities. Similarly, no effect was found for having siblings or time spent outdoors. Finally, no predictive effect was found from parenting style and parenting stress.

A limitation of SPLASHY is that we have only two measurement points within a relatively short period, just one year. Further measurement points later in development would be desirable to define predictors of EFs more precisely. Some factors which did not show an effect on EFs in preschool age might do so later. Furthermore, the coverage of this study is limited to typically developing children with minimal risk characteristics and psychopathologies. However, a clear strength of SPLASHY is that we examined a large sample representative of a typically developing community-based population of children within different social cultural regions of Switzerland and containing urban and rural communities with high and low SES. Another strength is that we compared different statistical analyses to prevent bias in the results.

Engelhardt et al. (2015) stated that, in contrast to adulthood, when the non-genetic variance from factors not based on biology, is rather small, the non-genetic variance of EFs in childhood is not yet clear. The current study contributes to answering this question. Our results indicate that genetic determinants may play an important role even at preschool age, because all predictors from different domains together accounted only for 32–36% of the variability in EFs, and among these, sex is also genetically determined. Further, consensus has yet to be reached on the extent to which motor skills and cognitive functioning are dependent on predisposition and environment. Thus, a part of the variance our predictors could explain in EFs is genetically determined, with the consequence that the definitely non-genetic variance is even lower.

Another aspect that should be investigated further is the relation between fine motor skills, cognitive functioning, and EFs. This study found that fine motor skills and visual perception predicted EFs, but other studies also found evidence that EFs are needed for complex motor and cognitive tasks and so might themselves be a source of motor and cognitive performance (Livesey et al., 2006; Roebers & Kauer, 2009).

Overall, we hat to accept that not so many factors in the preschool age period that predict EFs can be influenced by parents and professionals. Variables that might be influenced, such as parenting style, physical activity, time spent outdoors, and days in a child care center, did not predict EFs. Given our result, encouraging motor skills and cognitive functioning could be beneficial to EFs. Additionally, high SES was positively associated with higher EFs. Thus, children coming from families with low SES might be a vulnerable group regarding EF development, so this group would likely benefit most from interventions. Conversely, promotion of EFs might be of little use and even unnecessary for children from middle and high SES families. An alternative explanation is that families with high SES may already stimulate the development of EFs through factors that we have not directly investigated. As mentioned above, diverse factors such as home environment, childhood experience, stimulation in childhood, health care access, early life stress, and neighborhood conditions are all linked to SES and may all influence the development of EFs. Further studies should focus on a more precise investigation of the influence of the factors linked to SES on EFs. Finally, EFs in the age range we assessed are only starting to develop and are not yet stable. This instability might have contributed to the low predictive value of the factors we studied. However, this also implies that preschool age is a sensible age at which to support EF development, because the main components that lay the foundation for later EFs are still developing during this time. Thus, more longitudinal studies, including later time points in development such as school age, are needed in the future.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

AEZ wrote the manuscript and analyzed the data. AEZ, THK, NM, KS, CSL, EAS and AA recruited, tested, and collected the data. AHM assisted in statistical data analysis. SK, SM, JJP, and OGJ conceived and designed the SPLASHY study. All authors reviewed the manuscript and approved the final version for submission.

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4.4 The validity of parental reports on motor skills level performance in preschool children: A comparison with a standardized motor test

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Abstract

Motor skills are interrelated with essential domains of childhood such as cognitive and social development. Thus, the evaluation of motor skills and the identification of atypical or delayed motor development is crucial in pediatric practice (e.g., during well-child visits). Parental reports on motor skills may serve as possible indicators to decide whether further assessment of a child is necessary or not. We compared parental reports on fundamental motor skills performance level (e.g., hopping, throwing), based on questions frequently asked in pediatric practice, with a standardized motor test in 389 children (46.5% girls / 53.5% boys, *M* age = 3.8 yrs., *SD* = 0.5, range 3.0 – 5.0 yrs.) from the Swiss Preschoolers' Health Study (SPLASHY). Motor skills were examined using the Zurich Neuromotor Assessment 3-5 (ZNA3-5) and parents filled in an online questionnaire on fundamental motor skills performance level. The results showed that the answers from the parental report correlated only weakly with the objectively assessed motor skills ($r = .225$, $p < .001$). *Conclusion:* Although a parental screening instrument for motor skills would be desirable, the parent's report used in this study was not a valid indicator for children's fundamental motor skills. Thus, we may recommend to objectively examine motor skills in clinical practice and not to exclusively rely on parental report.

Introduction

Motor skills are interrelated with a number of developmental domains such as cognition, perception, language, social and physical development (Bar-Haim & Bart, 2006; Barnett et al., 2009; Diamond, 2000, 2007; Iverson, 2010; Rosenbaum et al., 2001). For example, Cameron et al. (2012) reported that in 3-4-year-olds motor skills correlated positively with performance in a Kindergarten achievement test, including language skills (e.g., reading, vocabulary and phonological awareness), and mathematical problems. Michel et al. (2011b) found that 5-7-years-old children with impaired motor skills showed lower pre-academic skills and lower performance in inhibition tasks compared to children without motor impairments.

Furthermore, several studies showed that fundamental motor skills (FMS) are essential for the engagement in physical activities and to discover the environment (Barnett et al., 2009; Stodden et al., 2008). FMS include locomotor (e.g., moving from place to place: walking, running, jumping, skipping, hopping, sliding, etc.) and object control skills (e.g., throwing, catching, kicking) (Haywood & Getchell, 2005; Stodden et al., 2008). Therefore, the competence in FMS is linked to health-related outcomes such as cardiorespiratory fitness, muscular strength and body weight (Lubans et al., 2010; Robinson et al., 2015). Stodden and co-workers stated that children who perceive their motor competence as low engage less in physical activity and, thus, bear a higher risk of becoming unfit and obese (Stodden et al., 2008). Both reduced physical activity and high body weight further promote low perception of motor competence which will eventually result in even lower motor competence (Stodden et al., 2008). As a result, children find themselves in a ‘negative spiral of disengagement’ (Stodden et al., 2008). In fact, less engagement in physical activities can also affect the social interaction with peers negatively, especially in the preschool age, and may lead to social exclusion (Bar-Haim & Bart, 2006; Smyth & Anderson, 2000). Smyth and Anderson (2000) found that children with developmental coordination disorder (DCD) spent more time alone or were more watching other children play compared to children without motor difficulties. These authors discussed that children with DCD might be excluded first from physical and then from social games. Moreover, potential co-occurring difficulties (e.g., cognitive deficits, language impairment etc.) might have an additional influence on the exclusion. However, actual causality remains open.

To avoid this negative spiral, it is important to assess motor performance early enough so that therapeutic intervention and support for the child may be introduced. Thus, the evaluation of FMS performance level in early childhood and the identification of atypical or delayed motor development is crucial in pediatric practice. In fact, pediatricians regularly assess FMS performance level during well-child visits by asking parents whether their child can already perform a certain task (e.g., climbing stairs, riding a bicycle, swimming) (Baumann & Pellaud, 2011; Jenni & Largo, 2014). Parental reports are an attractive option for receiving information about the development of the child. They are time and cost effective, and easy to implement. Parents have knowledge of the unaffected behavior and the skills of their children, whereas in clinical practice motivation and cooperation of the child may lead to ambiguous evaluation. Although evidence exists that parents provide valid and reliable reports regarding early motor milestones during the first years of life (Bodnarchuk & Eaton, 2004; Libertus & Landa, 2013; Majnemer & Rosenblatt, 1994), we do not know whether FMS performance level reported by parents during the preschool years ultimately reflect the child's performance in a standardized motor test. To our knowledge, there is no study examining parental reports on motor skills in typically developing preschool children (which was also state in (Miller, Perkins, Dai, & Fein, 2017)). In pediatric practice, it would be beneficial to know whether questions on daily motor activities of the child correlate with motor skills measured by a standardized test. Questions about daily motor activities aim to identify indicators for motor skills performance level. So far, it has not been examined whether these questions deliver some additional information on motor development.

Thus, we constructed a 6-item questionnaire of FMS based on questions frequently asked in pediatric practice (Baumann & Pellaud, 2011; Jenni & Largo, 2014) and compared the answers with objectively measured FMS performance level using the Zurich Neuromotor Assessment 3-5 (ZNA3-5), a standardized test instrument with good psychometric properties. Our aim was to evaluate whether a parental report on FMS performance level observed in everyday activities can deliver valid data about the level of motor skills development in the preschool age as measured by a standardized test procedure.

Materials and Method

Participants

Our analysis included 389 children between 3 and 5 years of age (181 girls/208 boys, *M* age = 3.8 yrs., *SD* = 0.5, range 3.0 – 5.0 yrs.). The data presented here were collected within the Swiss Preschoolers' Health Study (SPLASHY) that investigated typically developing preschool children in 84 child care centers (Messerli-Burgy et al., 2016). Originally, 476 children participated in the SPLASHY study. For this analysis, we excluded children below the age of 3 years and above the age of 5 years. From this sample (n=417), 24 parents did not fill out the motor questionnaire. Out of the remaining 393 parents, 389 parents answered at least three items, so that a total parental report score could be calculated.

Measurements

Motor skills were examined using the ZNA3-5 (Kakebeeke et al., 2013). The ZNA3–5 is based on the original ZNA for children older than five years (ZNA 5–18; (Largo, Rousson, Caflisch, & Jenni, 2007a; Largo et al., 2001b)) and is a well-standardized motor test instrument. The ZNA3-5 has a moderate to high intra-observer (kw = 0.56-1.00) and inter-observer (kw = 0.42-0.99) reliability, while test-retest reliability is lower in some tasks (0.35-0.84) (Kakebeeke et al., 2013).

Fundamental motor skills were measured with static balance (standing on one leg) and dynamic balance (walking on a straight line, hopping on one leg, side-to-side jumping and running). The instruction for static balance was "stand on your right/left leg as long as you can".

Timing started when the child lifted one foot off the floor and stopped when the child touched the floor with the lifted foot, or shifted the foot of the standing leg more than 2 cm, or when the time limit of 30 seconds was reached. Instructions for the dynamic balance tasks were the following; 1. Walking on a straight line: the child was asked to walk on the cord by putting one foot in front of the other. The heel of the anterior foot had to touch the toes of the foot behind. A qualitative score was given from 0 to 4 (0 = Perfect performance, heel touching toes; 1 = Distance between the two feet, feet straight; 2 = Feet not straight and/or misses the line 1-3 times; 3 = Feet perpendicular and/or does not touch the line > 3 times; 4 = Not able to walk with both feet on the line). 2. Hopping on one leg: the child has to hop as many times as possible on one leg, next to the cord. The task was done for each leg, and two trials for each leg were given. A qualitative score was given from 0 to 4 (0 = Can hop on both legs more than 7 times; 1 = Can hop on only one leg more than 3 times; 2= Can hop on both legs from 1 to 3 times; 3 = Can hop on only one leg from 1 to 3 times; 4 = Cannot hop on either leg). 3. Side-to-side jumping: the child was asked to stand beside the cord and to jump forth and back over the cord sideways while keeping the feet together. A qualitative score was given from 0 to 4 (0 = Perfect performance, very smooth jumping; 1 = Jumping is correct but not very smooth; 2 = Touchdown with two feet at the same time, jumping very stiff; 3 = Total body involvement, poor coordination in relation to the line direction; 4 = Jumping about but not in relation to the line). 4. Running: the child had to run 20 meters around the chairs (5 x 4 meter). A qualitative score was given form 0 to 4 (0 = Rolling motion of feet with adjustment of upper body; 1 = Rolling motion of feet, stiff upper body; 2 = Running with partial rolling motion of feet; 3 = Running without any rolling motion of feet; 4 = Cannot run (no flight phase)). For the analyses, all ZNA3-5 performance was expressed as standard deviation scores (SDS) calculated from age- and sex-adjusted normative values. Positive values corresponding to above average performance and negative values to below average performance.

Parents filled out an online questionnaire containing questions about swimming, climbing stairs, hopping, riding, balancing and throwing (Table 1). For each FMS item the parents had to rate the stage of development. Responses were combined into three categories: 0 – 1 – 2 (Table). A sum score for the parental FMS questionnaire (parental FMSQ) was calculated by taking the average score across the six items (if at least three items were answered), multiplied by the amount of all items.

Statistical analyses

Statistical analyses were performed using SPSS (IBM, SPSS; Version 22.0, Chicago, IL, USA). Descriptive statistics were calculated by means ± standard deviations for continuous variables and percentages for categorical variables. The main outcome variables ZNA scores and sum parental FMSQ score were normally distributed. For parental FMSQ sex effects were tested with the Mann-Whitney-U-Test and age effects with Spearman's rank order correlations. Corresponding effect size were calculated. SDS scores for ZNA were sex and age-adjusted and therefore these effects were no more examined. The relationship between ZNA outcome and parental FMSQ outcome was investigated using partial correlation, with age and sex as control variables. Furthermore, the sample was divided in three tertiles by age to test whether parental report delivers reliable information for all age groups in the preschool age: first tertile n = 129, *M* = 3.3 yrs., range: 3.0 – 3.5; second tertile n = 130, *M* = 3.8 yrs., range: 3.5 – 4.1 and third tertile n = 130, *M* = 4.4 yrs., range: 4.1 – 5.0. Partial correlations were compared with Spearman's rank order correlations, which are more adequate for ordinal variables but do not allow to include control variables. Correlations from both analyses were very similar in magnitude and significance level (Table 2). Therefore, only partial correlations controlled for age and sex are discussed.

Results

Parental FMSQ scores ranged from 3 to 12 with a mean sum score of *Median* = 8.00 (*SD* = 1.80) (Figure 1). Frequencies of each answer category per items are shown in Table .

There was no sex difference in the sum score of the parental FMSQ, (p = .31), while we found small sex differences for the items riding, U = 16273.0, p < .05 (effect size r = .14), and throwing, U = 13781.0, p < .05 , (effect size r = .12), with boys showing a higher score on both items. Furthermore, there was a strong age effect$r$ = .506, p < .001 ; older children scored higher than younger children. The internal consistency between the six FMSQ items was expressed by a Cronbach alpha of .50.

The questionnaire was mainly filled out by mothers (84.3%, in 14.7% exclusively by the fathers). We compared the children included in the analyses with the 24 excluded children without motor questionnaire data; they did not differ in age, sex, SES, and the tested ZNA tasks (p < .05). ZNA scores were age and sex adjusted, therefore no corresponding effects can be reported.

Overall, the parental FMSQ correlated weakly to moderately with the ZNA total dynamic balance tasks, r = .225, p < .001 and weakly with static balance r = .137, p < .05. The FMSQ item jump revealed the strongest correlations with ZNA outcomes (Table 2), significant correlations were found between jumping and walking on a straight line, hopping on one leg and total dynamic balance (r = .158 – .228) (Table 2). The three items stairs, ride and balance correlated with several tasks from the ZNA, while the items swim and throw did not correlate with any tasks from the ZNA.

The same partial correlations between ZNA motor tasks and the FMSQ items were performed for three different age groups. Correlations for parental FMSQ sum and ZNA total dynamic balance were nearly the same in all age groups (r = .196 - .284, p < .05). As for the overall analysis, the item jump from the FMSQ correlated most frequently and strongest with ZNA tasks in all age groups (r = .220 - .325), while swim and throw were not correlated with any of the ZNA tasks. Between the three age groups differences occurred, but no systematic differences in amount or magnitude of significant correlation was observed. Correlations only significant in a single age group were the following; only in the youngest group static balance

(ZNA) was correlated with FMSQ sum (.307, p = .003) and stairs (.276, p = .009), and, only in the middle group the item stairs (FMSQ) and walking on a straight line (ZNA) were correlated (.232, p =.020). The item balance (FMSQ) and running (ZNA) were correlated in the first and second group (.290 /.265, $p < .05$).

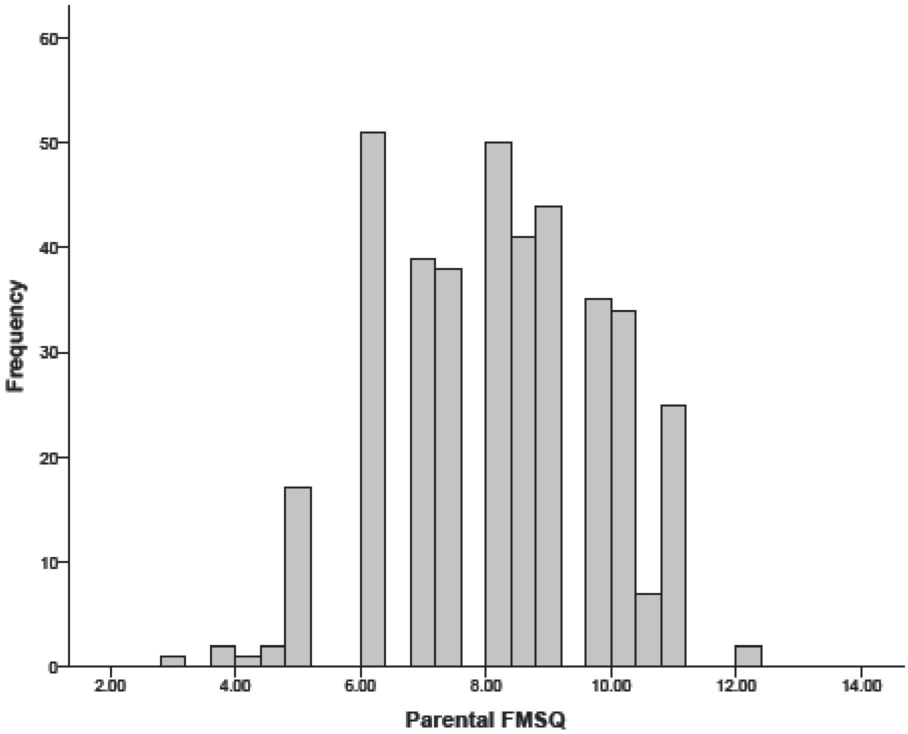

Figure 1. *Frequency distribution of the parental report sum score.*

Table 1. *Items and descriptive statistics of parental report on FMS assessed by questionnaire (frequency distribution).*

points	*Questionnaire items*	*frequency in %*				*n*
		1. T	*2. T*	*3. T*	*all*	*total*
	Swimming					*375*
0	Cannot swim	46.3	30.5	27.6	34.1	
1	Can swim with swimming aid	53.7	66.2	63.8	61.9	
2	Can swim without swimming aid	0.0	3.3	8.6	4.0	
	Climbing stairs					*366*
0	Cannot climb stairs or only by crawling on all fours	1.0	0.7	0.0	0.5	
1	Can climb stairs in upright posture, but holds the banister	13.3	5.7	3.3	7.1	
2	Can climb the stairs in upright posture without holding the banister	85.7	93.6	96.7	92.3	
	Jumping					*376*
0	Cannot jump	2.9	3.4	0.0	2.1	
1	Can jump with both legs	58.1	43.0	16.4	38.6	
2	Can jump on one leg	39.0	53.7	83.6	59.3	
	Riding					*387*
0	Cannot ride bicycle/scooter/tricycle/tractor with support wheels	1.9	0.6	1.6	1.3	
1	Can ride tricycle/scooter/balance bicycle/bicycle with support wheels	93.5	74.8	50.0	72.1	
2	Can ride a bicycle without support wheels	4.6	24.5	48.4	26.6	
	Balance					*261*
0	Can neither balance forwards or backwards on a bar	19.3	11.4	1.0	9.2	
1	Can balance forwards on a bar (at least 8 steps)	70.2	77.1	71.7	73.6	
2	Can balance forwards and backwards on a bar (at least 8 steps)	10.5	11.4	27.3	17.2	
	Throwing					*355*
0	Cannot catch a ball	7.0	6.4	1.7	5.1	
1	Can catch or throw targeted	54.0	38.6	19.1	36.6	
2	Can catch and throw targeted	39.0	55.0	79.1	58.3	

Note. Descriptive statistics are presented for the entire sample (all), and for the sample divided in three tertile groups, *T* = tertile,

Table 2. *Association between parental fundamental motor skill questionnaire (FMSQ) and ZNA motor skills scores; above the diagonal, correlation coefficients controlled for age and sex are presented, under the diagonal, spearman correlation coefficients are presented.*

	1	2	3	4	5	6	7	8	9	10	11	12	13
ZNA3-5													
1. Static balance		**.326****	.144*	**.207****	.120*	**.321****	.007	.121*	.072	.163**	.006	.064	.137*
2. Walk on a line	**.307****		**.225****	**.212****	.172**	**.660****	.070	.133*	.158**	.069	.010	.055	.151**
3. Jump side-to-side	.165**	**.212****		.137*	.121*	**.618****	.018	.065	.094	.075	-.095	.052	.097
4. Hop on one leg	.178**	**.190****	.136*		.099	**.593****	-.059	.111	**.215****	.130*	.045	.004	.154*
5. Run	.080	.116*	.133*	.088		**.584****	-.006	.036	.094	.072	.224**	.040	.145**
6. Total dynamic balance	**.304****	**.621****	**.590****	**.584****	**.544****		.016	.123*	**.228****	.138*	.087	.066	**.225****
FMSQ													
7. Swim	.039	.063	.025	-.040	-.034	.027		.009	.079	.179**	.028	-.004	**.504****
8. Stairs	.147*	.137*	.078	.144*	.016	.166**	.036		**.198****	.061	.004	.030	**.346****
9. Jump	.086	.165**	.095	.238**	.025	**.240****	.166**	**.195****		.145**	.190**	.162**	**.603****
10. Ride	.172**	.066	.072	.141*	.008	.131*	**.233****	.095	.265**		-.001	.022	**.462****
11. Balance	-.011	.018	-.095	.048	.123	.080	.082	.040	**.273****	.093		-.009	**.453****
12. Throw	.074	.070	.044	.023	-.017	.072	.048	.052	**.241****	.158**	.068		**.510****
13. Sum FMSQ	.142*	.131*	.165**	.178**	.080	**.304****	**.515****	**.304****	**.678****	**.573****	**.494****	**.567****	

Note. Significant correlations * $p < .05$, ** $p < .01$, ** $p < .001$ are presented in **bold.**

Discussion

The findings of this analysis of the SPLASHY data showed that the rating of FMS performance level by parents correlated weakly to moderately with standardized measured FMS performance level in the preschool age. Out of the six questioned motor skills four items - climbing stairs, jumping, riding and balancing - correlated weakly with measured motor skills. Swimming and throwing did not correlate with any motor tasks from the ZNA.

Climbing stairs, jumping and riding from the FMSQ were correlated weakly with measured total dynamic balance and single tasks from the ZNA static balance, walking on a straight line and hopping on one leg. The item jump from the FMSQ correlated slightly stronger with ZNA outcomes than climbing stairs and riding, still, the correlation found between jump and the corresponding ZNA tasks hopping on one leg was weak to moderate. No correlations were found between FMSQ items and side-to-side jumping. Balance from the FMSQ was correlated only with running. This is surprising because the performed ZNA tasks, walking on a straight line, side-to-side jumping and hopping on one leg substantially include balancing skills, even though, more than running. Another unexpected result was that static balance, measured separately, did also not correlate with balance from the FMSQ. A reason might be that 33% of the parents did not know whether their child can balance, so for the item balance fewer children were included, which can result in a power problem. However, the correlation coefficients were below .10, so there was truly no significant association.

The items swim and throw did not correlate with any task from the ZNA. The report on swimming might be influenced more by the environment, such as the opportunity to learn swimming than the actual motor competence. The ZNA did not include object control, so it was not expected that throwing would correlate high with other FMS. The analysis separated for different age groups revealed some weak and moderate, significant correlation but confirmed altogether the weak association between FMSQ and ZNA.

The internal consistency of the FMSQ was rather low indicating that single items may not measure a unique construct. Given the diversity of the items asked, this finding was expected. As we also examined and reported results of single items, low internal consistency is no strong limitation for the study. An explanation for the generally weak correlations could be that the variability within the items was sometimes too small, for example, only 0.5 % reported that their child could not climb stairs, but over 90 % could climb the stairs without holding the banister. It could also be that parents do not provide valid data on children's FMS performance level during the preschool years. Other studies have shown that parental reports on motor milestones in the first two years are a valid marker of motor development of infants (Bodnarchuk & Eaton, 2004; Libertus & Landa, 2013) indicating that parents deliver valid data about the motor competence of their child. This current study shows that this may not be the case as children grow older. The parental report may also not be valid because parents may not have had the opportunity to observe the questioned FMS if they do not spend much time with their children or spend time doing activities for which no FMS are needed. However, only for the item balancing parents reported not to know if their child can balance. Further, certain items such as ride or swim can be related to not having much opportunity to swim or ride rather than be an indicator of the motor skill level. The low correlations between the questionnaire items and the ZNA outcomes may be explained by our sample that included only typically developing children. There is evidence that parental reports in clinical populations are more valid (Miller et al., 2017). Miller et al. (2017) reported in a sample of two-years-olds with developmental disorders (e.g., autism, global developmental delay, developmental language disorder) that parental report on language and fine motor skills did not differ significantly from the measured skills. Finally, the asked and tested motor skills were possibly too different in their nature. Although all skills are indicators for gross motor competence, the asked items are more complex motor skills, while the tested skills are more basic motor skills. In this context, it has to be mentioned that the ZNA3-5 primarily measures motor abilities, which - to a large extend -

cannot be practiced and are not dependent on the environment (Jenni et al., 2011). In fact, a motor test focusing more on skills may correlate higher with the parental report presented in this study.

Some limitations of the study need to be mentioned. For instance, the variability within certain items was small (e.g., for the item balance, 33% of the parents reported not to know the level of performance). The internal consistency of the FMSQ was rather low. Moreover, we did not ask if the child had the opportunity to do all the tasks. However, the percentage of children not able to swim or ride a bike was according to age.

In sum, parental report presented in this study did not provide valid data on motor development, tested by the ZNA3-5 in preschoolers. A parental report may be a valid instrument, if the items are further adapted: The items should not be strongly dependent on the environment of the child (e.g., opportunity to swim) and better differentiate between children with varying motor skills within the same age group (e.g., more categories per item). However, whether parental questions really allow a valid description of motor development and identification of children with delayed motor development remains unclear. Thus, we conclude that the evaluation of FMS performance level in healthy preschool children by their parents may not replace an objective examination of the motor skills with standardized instruments. Parental report may be considered as a screening instrument in combination with an objective examination. Given the importance of motor development due to the interrelatedness with other developmental domains and social interactions, efforts to facilitate the best possible assessment of motor development should be pursued.

Compliance with Ethical Statements

Conflict of interest

The authors declare that they have no conflict of interest.

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Informed consent

Informed consent was obtained from all individual participants included in the study: Parents provided written informed consent for their participating child and children consented orally.

Authors' contributions

AEZ: performed data collection, wrote the manuscript and analysed the corresponding data.

THK, NMB, KS, CLA, EAS, AA: performed data collection.

AHM: assisted in statistical data analysis.

VF: contributed to the draft and data analysis of the manuscript.

SK, SM, JJP, OGJ: conceived and designed the SPLASHY study.

All authors reviewed and edited the manuscript.

5

Discussion

The overall aim of this thesis was to assess the stability of motor and cognitive skills at preschool age, to examine the predictive value of these abilities for their own and other domains, to understand the associations between motor skills, cognitive skills and EFs, and to examine individual and interpersonal predictors of EFs.

5.1 Stability and prediction of motor and cognitive skills in preschool age

Using a latent variable approach, we found that motor skills and cognitive skills are quite stable over one year in preschool years. This means that overall the high achievers from the first baseline measurement were also the high achievers in the first follow-up year. Given that other studies have found moderate to high stability values from school-aged to adolescence (Ahnert & Schneider, 2007; Jenni et al., 2011; Maia et al., 2001), our findings of high stability values from three to five years indicate that motor and cognitive performance in preschool age might be related to later motor and cognitive performance in school-aged and adolescent individuals.

This finding of high stability values for motor and cognitive skills in preschool age is important for clinical practice. At preschool age, children are seen regularly at pediatric well-child visits, where screening take place. Reliable screening depends on the stability of the developmental domains examined. Our study indicates that motor and cognitive development are reliable domains for screening and therefore reliable indicators for the identification of children at risk for delayed motor or cognitive development at preschool age. This makes early interventions possible. Early interventions are desirable because motor and cognitive skills are crucial factors in the development of children and have been found to predict school achievement (Bart, Hajami, & Bar-Haim, 2007; Roebers et al., 2014).

Furthermore, we found that overall motor skills predicted cognitive performance one year later, with a small effect size. This is in line with previous studies, although those studies often used fine motor skills instead of a total motor score (Cameron et al., 2012; Piek et al., 2008; Roebers et al., 2014). To compare these results, we conducted additional analyses for the sample

p overall

c predict

c

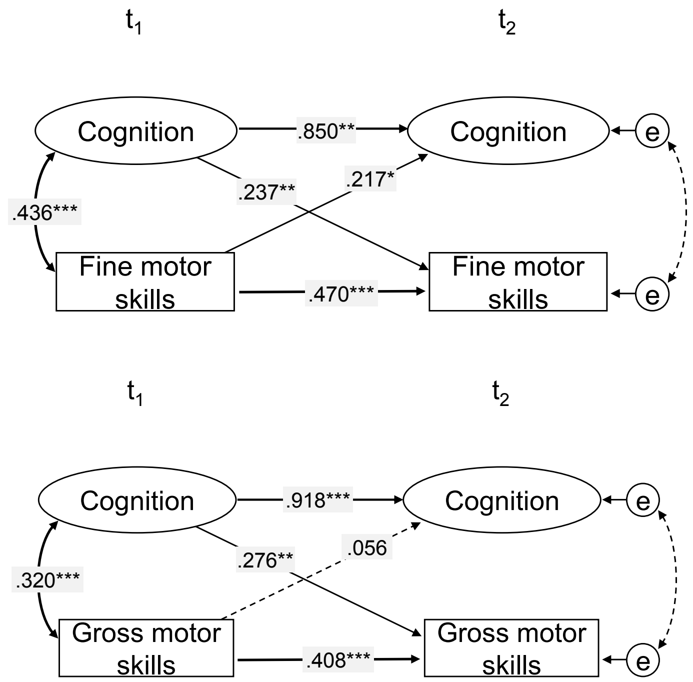

Figure 4. *Structural equation model examining the longitudinal (two measurement points T1 and T2) interrelation between fine and gross motor skills and cognitive functioning (latent variable measured by visual perception; selective attention; visuo-spatial working memory; figural reasoning). * p > .05; ** p < .01; *** p < .001; non-significant paths are presented in dashed lines; e = error term.*

In our original study, cognitive skills did not predict overall motor skills significantly one year later. However, in the additional analysis, cognitive skills predicted fine and gross motor skills with small effect sizes. An explanation might be that gross motor skills are more complex, so cognitive skills are needed to understand instructions and perform the tasks, especially in young children. The fine motor skills task was demanding in terms of attention and speed but overall rather simple. A further explanation is that this additional analysis compares a latent variable and a single observed variable. As discussed in 4.1, in the discussion of the paper (p. 44), using a latent variable approach reduces measurement errors and so leads to increased coefficients. Because we replaced the latent motor skills variable here with an observed variable, the latent variable cognition has more predictive power. To our knowledge, no other studies have reported that cognitive skills predicted motor skills (Roebers et al., 2014). Thus, in comparison with previous studies, the finding that overall and fine motor skills predict cognitive skills seems more robust than cognition predicting motor performance.

Thus, future intervention studies should test the effect of encouragement of motor skills on cognitive development in early childhood. In a recent systematic review and meta-analysis, Wick et al. (2017) examined the effect of interventions on fundamental motor skills (include object control and locomotor skills) in preschool-age children. These authors reported that overall the intervention groups profited in comparison to the control groups; however, the effects sized differed substantially. Wick and colleagues suggested further high-quality research to increase the certainty of the evidence. Thus, it is possible to train fundamental motor skills at preschool age, but the benefit of interventions such as effects on cognitive skills has to be examined in greater depth. An additional reason to promote motor skills is given by evidence that motor competence might promote physical activity (Stodden, Langendorfer, & Roberton, 2009). Moreover, evidence supports the idea that acute and regular physical activity in schoolaged children and adults can have a beneficial effect on cognitive performance and EFs (Ahn & Fedewa, 2011; Tomporowski, Davis, Miller, & Naglieri, 2008; Tomporowski, McCullick, M. Pendleton, & Pesce, 2015). Hence, motor skills might influence cognitive skills in different ways, including through indirect paths via physical activity. This assumption is discussed further in Chapter 5.3.

5.2 Are motor and cognitive inhibition interrelated during development?

We tested the hypothesis that inhibition processes have a common basis and thus that immaturity of the prefrontal cortex may cause increased associated movement and limited cognitive inhibitory control. We investigated the association between motor inhibition (associated movements), cognitive inhibition (self-regulation, selective attention), working memory, visual perception, and figural reasoning. Results showed that self-regulation and selective attention were moderately associated with motor inhibition: the more associated movements the children showed during the motor test, the worse was their performance in the statue test and selective attention task. Additionally, visual perception was associated with associated movements, while working memory and figural reasoning were not significantly related with associated movements. The connection of visual perception with inhibition was somewhat surprising. An explanation is that this task may also be associated with the same maturation processes that are linked with inhibition. In preschool age, associated movements are often seen during difficult motor tasks, but these movements decrease with age. Therefore, these movements are assumed to be an indicator of cortical maturation (Gaddis et al., 2015). Our results support the hypothesis that the immaturity of cortical maturation in preschoolers leads to poor performance in both motor and cognitive inhibition.

5.3 Which factors influence the development of executive functions, and which of them are modifiable?

We examined the predictive value of individual demographic, biological, psychological, and interpersonal factors thatrefer to the environment of the child, such as parenting style and stress, the presence of siblings in the household, and the number of days spend in child care centers (Figure **5**). We found that sex, SES, and fine motor and cognitive skills predicted EFs one year later with a small effect size and thus might have an influence on the development of EFs. Interpersonal factors did not predict EFs. Although cumulative evidence existed that positive parenting, same-age siblings, and high levels of physical activity influence EFs positively, no effect of these predictors was visible in our study. EFs at baseline predicted EFs one year later with a moderate effect size.

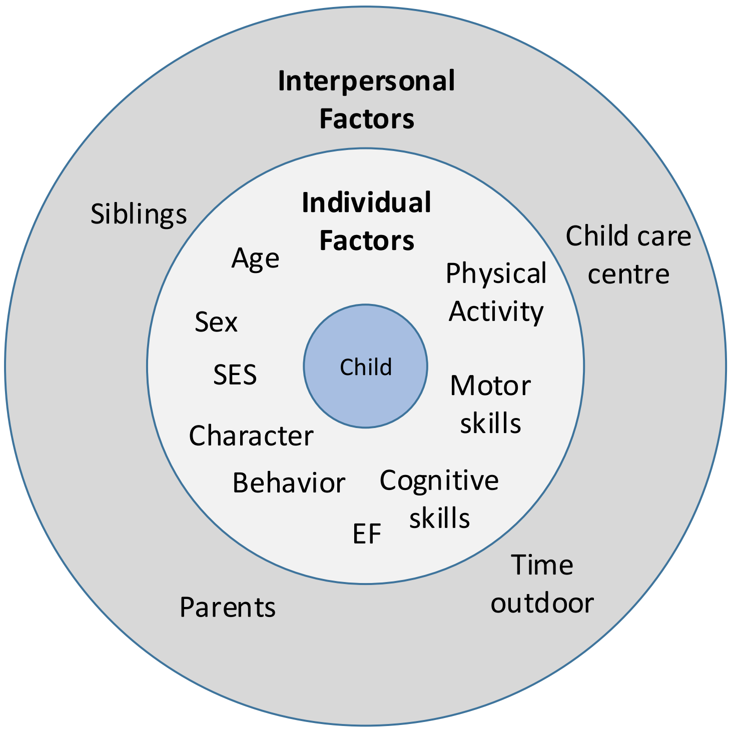

Figure 5. *Examined predictors of EFs (Character, Behavior and Parents are summarized predictors), presented in an adapted socioecological model (based on Bronfenbrenner's Model(Kail, 2004b)).*

An interesting finding was that level of SES predicted EFs. Previous studies had found an association between SES and cognitive functioning (Bradley & Corwyn, 2002). In a cross-sectional study by Noble et al. (2005), the association of SES with EFs was even larger than in our study, showing a moderate effect size. Children of low SES performed worse than children of middle SES in EFs tasks. Additionally, SES was positively associated with performance in language, but only a nonsignificant evidence was found for an association with visual cognition and visuospatial skills. This indicates that SES has no general effect on cognitive performance or that the effect of SES varies in terms of different skills. Noble and colleagues argued that measure of SES contains more than the variability in occupation, income and education. Other factors, such as the home environment, childhood experience, cognitive stimulation in childhood, health care access, early life stress, and neighborhood conditions, are closely linked with SES and might influence children's development (Bradley & Corwyn, 2002; Lupien et al., 2007; Lupien et al., 2009; Moriguchi, 2014; Noble et al., 2005).

In an overview, Bradley and Corwyn (2002) reported findings of various pathways through which factors related with SES can influence the cognitive development and health of children. For example, mothers who had opportunities for problem solving in their occupation showed more warmth and support in their parenting and provided more stimulating material (Parcel & Menaghan, 1990 in Bradley & Corwyn, 2002). Thus, experience at work influences parenting style. Our study could not support the result that parenting influences cognitive development; in our study, we found neither positive nor negative effects of positive or inconsistent parenting nor stress level of parents on EFs. A further explanation of an influence of SES on development is that low SES is often related to minority status, single parenthood, or family members with disability, which can create a stress-inducing environment (Garbarino, 1999 in Bradley & Corwyn, 2002). Moreover, children from low SES families are less often provided with stimulating material and experience (e.g., cultural activities and excursions), which is essential for cognitive development (Crowyn & Bradley, 2000 in Bradley & Corwyn, 2002). In sum, the availability of material and social resources and the stress reactions of parents and child might be factors central to SES that influence the cognitive development of children and development in general. The SPLASHY sample included children from low and high SESs, but few children were exposed to severe negative life events (e.g., severe illness of family member, divorce of parents) or other risk conditions (e.g., unemployment, alcohol abuse, violence, conflicts in partnership). The overall good well-being of the children in the sample may indicate that the environmental conditions are not dramatically different in our sample; this would explain the small effect size of SES on EFs in our study.

A further relation has been reported between SES, EFs, and language skills. In a study by Noble et al. (2005), SES and language skills both predicted EFs. However, when language skills were controlled for, SES explained no additional variance in EFs. That supports the assumption that language skills might affect EFs via the self-regulatory function of language; language skills are needed in several EFs tasks. For example, working memory performance depends on strategies that often include verbal rehearsal (Bjorklund, 2005b; Hughes & Graham, 2002). The SPLASHY study did not assess language skills, so the hypothesized causality path could not be tested. One hypothesis is that SES and related factors may have an influence on language skills that drives EFs performance (Bradley & Corwyn, 2002; Noble et al., 2005). However, the mechanism underlying the association of SES and EFs has not yet been fully elucidated.

We investigated the predictors fine motor skills, pure motor skills, and associated movements. Of these, only fine motor skills predicted development one year later. The finding that associated movement did not predict EFs is interesting, because in the paper on the association of motor inhibition and cognitive inhibition in preschoolers (see 4.2), we found that associated movement was correlated with two out of three components of EFs. Further, associated movement and speed of repetitive motor skills (pure motor) were found to predict academic achievement (Wolff, Gunnoe, & Cohen, 1985). Perhaps if we had analyzed predictors of the single components, associated movements would have emerged as a predictor. However, our result is not in line with the Gottwald et al. (2016) assumption that motor inhibition might be a first preliminary component of EFs. The introduction (3.3.2) has already discussed the assumed association of motor skills and cognitive functioning. Fine motor skills have more often been found to be associated with cognitive skills or EFs than other motor components (Cameron et al., 2012; Cameron, Cottone, Murrah, & Grissmer, 2016; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Roebers et al., 2014; Stöckel & Hughes, 2016). Cameron et al. (2016) stated in a review that motor components differ in predicting outcomes; fine motor skills are more associated with academic performance, while gross motor skills tend to be associated with social competences, physical well-being, and with engagement in social activities. That would support Stodden and colleagues' (Robinson et al., 2015; Stodden et al., 2008) theory that perceived motor competence might positively or negatively influence physical activity, health-related fitness, and risk of obesity. Healthy or unhealthy weight in turn is related to physical activity and again to perceived motor competence. Positive or negative perceived motor competence could thus lead to a *positive spiral of engagement* or a *negative spiral of disengagement*. For physical activity, gross motor skills and fundamental motor skills are more needed than fine motor skills, according the model of Stodden.

In despite of the assumption that fine motor skills are more related to cognitive skills, single studies have found that gross motor skills predicted EFs or cognitive skills (Oberer, Gashaj, & Roebers, 2017; Piek et al., 2008). Oberer et al. (2017) explained the unexpected result with their approach to measuring EFs; computerized tests were used instead of a test that measured inhibition behavior (e.g., “Head-Toes-Knee-Shoulder” in Cameron et al., 2012; "statue test" in Messerli-Burgy et al., 2016). Oberer et al. (2017) conclude that in previous studies the relation between gross motor skills and EFs may have been underestimated. In a study by Piek et al. (2008), fine and gross motor skills were assessed in children of 4 months to 4 years, so gross motor measures included posture control and early locomotion skills such as crawling and walking. These early gross motor skills predicted later cognitive performance, which would support Piaget’s thoughts (Chapter 3.3.1; Bjorklund, 2005c; Kail, 2004a). However, in our study on the stability and predictive value of motor and cognitive skills, both overall motor skills and fine motor skills predicted cognitive skills one year later, but gross motor skills did not (see Chapter 5.1).

In the previous chapter, we mentioned studies which found a beneficial effect of physical activity on cognitive skills and EFs (Chaddock et al., 2012; Hillman & Schott, 2013; Niederer et al., 2011; Tomporowski et al., 2015). To investigate this effect, we included moderate to vigorous physical activity as a predictor. Surprisingly, no effect was found in our study. Niederer et al. (2011) conducted one of the few long-term studies with preschoolers that investigated the effect of physical activity. Those authors found a small positive effect of baseline physical activity on attention and a small positive effect of dynamic balance on working memory.

Best (2010) and Tomporowski et al. (2015) reported that physical activity including greater cognitive engagement might lead to increased performance in cognitive and EFs tasks. Moreover, it might be that “EFs may be more sensitive to aerobic exercise at one developmental time point than at another, and one EFs component may be more sensitive to acute aerobic exercise than another” (Best, 2010, p. 6). Perhaps we should have included the single tasks of

EFs in addition to the component score to discover effects of physical activity on specific tasks. Moreover, in two-to-six-year-olds, an effect of physical activity might not yet be ascertainable because the EFs are not yet stable. Finally, the children in our sample generally met the recommended guidelines for physical activity (min. 180 min/day total physical activity and min. 60 min/day moderate to vigorous physical activity; (Leeger-Aschmann et al., 2016)). Thus, we had a physically active and healthy sample. These factors might explain why no effect of physical activity could be found in our sample.

An interesting question for further studies would be whether the factors that predicted EFs would be the same for motor and cognitive skills. For example, SES was found to predict fine motor skills and cognitive skills, but not gross motor skill in the study by Piek et al. (2008); the association of SES and cognitive skills was stronger than the association between SES and fine motor skills.

5.4 Practical implementation: parental report on fundamental motor skills

Findings from this thesis support previous results, which found that motor skills might predict cognitive skills and EFs. Moreover, as reported in the introduction, motor skills are important for daily activities and social participation. To avoid the negative consequences of atypical or delayed motor skills, it is important to assess motor performance early. Based on this background, we investigated an approach to improve the identification of delayed or atypical motor development. We examined the suitability of a parental report on daily motor skills by comparing the results from the parental report with a standardized motor test. Results showed that the two outcomes correlated only weakly, indicating that the parental report we tested may not be applicable for detecting children at risk for atypical or delayed motor development. Therefore, an objectively examination of motor skills is recommended for clinical practice.

5.5 Review of SPLASHY

To improve the health of children, it is crucial to identify the influences of potential risk factors or beneficial resource factors. This may lead to advances in understanding the mechanisms underlying positive or negative health outcome. Therefore, the SPLASHY study was conducted to examine the influence of stress and physical activity on children’s psychological health (cognitive functioning, psychological well-being) and physiological health (adiposity and motor skills).

A major advantage was the interdisciplinary approach, which combined a variety of exercises in the field of child development and child health. This approach enabled the study of associations and influences from a broad range of individual and environment factors (for overview, see Table **1**). The diversity of factors, which were measured mostly with objective and well validated instruments and the combination of direct and indirect assessment, including information from children, parents, and child care educators, is a certainly a strength. We assessed these factors at preschool age because it represents a possibly vulnerable period in child development, but intervention can take place to reduce (e.g., stress-inducing situation) or promote (e.g., physical activity) relevant factors. SPLASHY was the first study that investigated these factors in preschool children in a longitudinal design. Another strength of the study was a large community-based healthy cohort, including children from two socio-culturally different regions within Switzerland. The exclusion criteria were kept to a minimum to gather large external variability.

5.5.1 Limitations

A first limitation occurred during the recruitment of children in child care centers: the participation rate was lower than expected, so recruitment had to be extended. The final sample size is satisfactory, but for certain measures (e.g., saliva samples), more data would have increased the validity. Furthermore, the coverage of these studies is limited to typically developing children, with minimal risk characteristics or psychopathologies. It also only included children who attended a child care center. Although the aim was to have a typically developing cohort, the final sample may underrepresent children at risk, which would be needed to represent the Swiss population completely. Moreover, the participation was limited to families and children that understood German or French, because the questionnaires were only available in these languages. This may have excluded families with migration background and families from the Italian and Rhaeto-Romance areas. These two regions of Switzerland were not included for logistical reasons. So far, only two measurement points have been assessed, with a rather short time span of one year between the measurement points. Further measurement points later in development would be desirable to examine predictors, influences, and stability over a longer timespan and identify factors that predict outcomes at older ages.

5.5.2 Proposals for the follow-up of the SPLASHY project

The further investigation of the association between motor and cognitive skills, and EFs requires that three types of additional information are gathered.

First, the language skills of the children should be examined, because these could predict EFs and might mediate the relationship between SES and EFs. It is challenging to measure EFs in preschool children because complex high-demand tasks are not feasible at this age and have to be age-adapted. A further issue is presented by the limited language skills. EFs tasks for school-aged children and adolescents often require language skills. For example, in the Stroop Color–Word Task (Stroop, 1935), words of colors are presented in different colors (e.g., “green” is printed in red) and the participant has to switch between reading the word (“green”) or naming the color the word is printed in (red). Thus, the tasks for EFs can be adapted as the language skills of our SPLASHY cohort increase.

Second, in line with language skills, it would be very interesting to assess whether the child uses a strategy during cognitive or EFs tasks. For example, performance in working-memory tasks is limited in preschool children due to lack of strategy knowledge in addition to the restricted vocabulary (Hughes & Graham, 2002). In working-memory tasks, school-aged and older children often use verbal strategies, such as labeling and rehearsal of the objects/numbers that have to be memorized. Thus, verbal strategies support the working-memory capacity, so increased working-memory capacity enables more complex rules to be memorized; these are needed in every EFs task. Further, language is assumed to have a self-regulatory function (Bjorklund, 2005b), which also encourages performance of EFs. In sum, language skills and verbal strategies are important factors for cognitive skills and EFs and should be considered in further examinations.

Third, the specific predictive value of fine and gross motor skills and associated movements on cognitive skills and EFs should be investigated in greater depth. The perceived motor competence of the child could be considered. In the model proposed by Stodden et al. (2008), perceived motor competence in early childhood was related to actual motor performance and physical activity. Stodden included body weight as outcome in his model. Cognitive performance could be added as an adaptation. There is evidence that children’s perception of their own competence is broadly accurate, and the perception and actual motor performance is related to physical activity (Duncan, Jones, O'Brien, Barnett, & Eyre, 2018; Stodden et al., 2008; Stodden, Gao, Goodway, & Langendorfer, 2014).

5.6 Conclusion and Implications

The findings of the studies presented here indicate that development in certain domains of motor and cognitive skills and EFs may be related and can predict each other's outcome later in development in early childhood. Fine motor skills especially seem to be a predictor for cognitive and EFs performance. Biological and demographic factors were found to be important predictors for EFs and thus may influence cognitive development. However, the finding that factors that are less modifiable are the most predictive ones indicate that outside influences through prevention and intervention might be limited to support the motor and cognitive development. Support for this assumption comes from the rather high stability of motor and cognitive skills that we found in early childhood. Consequently, interventions for supporting the development of specific skills should be targeted and focus on children at risk (e.g., children from low SES). What may be more beneficial than focusing only on the delayed or atypical attributes of a child may be to support the child and put stress on strengths; these may compensate for deficits or impairments.

6

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Curriculum Vitae

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Education

10/2013 – present	PhD student at the University Children's Hospital Zurich, Child Development Centre and the PhD program at the University of Zurich, Department of Psychology
09/2009 – 08/2011	Master of Science (MSc) in Psychology at the University of Bern, Majors: Developmental Psychology and Clinical Psychology
09/2006 – 08/2009	Bachelor in Psychology (BSc) at the University of Bern
08/2002 – 07/2006	Kantonsschule Solothurn

Professional experience

10/2013 – present	University Children's Hospital Zurich, Child Development Center, PhD student
08/2012 – 05/2013	University of Teacher Education Zug, Institute for the Management and Economics of Education (IBB), research internship
10/2011 – 07/2012	Special need education Solothurn, early intervention internship
02/2011 – 05/2011	School Psychology Services Muri, regional office Wohlen, internship

Grants

02/2017	Travel Grant, University of Zurich, Department of Psychology

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Publication list

Peer-reviewed journal articles

2018 **Zysset, A.E.,** Kakebeeke, T.H., Messerli-Bürgy, N., Meyer, A.H., Stülb, K., Arhab, A., Leeger-Aschmann, C.S., Schmutz, E.A., Ferrazzini, V., Kriemler, S., Puder, J.J., Munsch, S., Jenni, O.G. (2018). The validity of parental reports on motor skills performance level in preschool children: A comparison with a standardized motor test. *European Journal of Pediatrics, 2018*

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2017 Kakebeeke, T.H., **Zysset, A.E.**, Messerli-Bürgy, N., Chaouch, A., Stülb, K., Leeger-Aschmann, C.S., Schmutz, E.A., Arhab, A., Rousson, V., Kriemler, S., Munsch, S., Puder, J.J., Jenni, O.G. (2017). Impact of

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Oral presentations

2017 **Annina E. Zysset,** Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. The stability and predictive value of motor skills and cognitive functioning in 2 to 6 year old preschool children: data from SPLASHY. Swiss Psychological Society Annual Congress, Lausanne, Switzerland, 09/2017. Oral presentation.

2016 **Annina E. Zysset**, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. The stability and predictive value of motor skills and cognitive functioning in 2 to 6 year old preschool children. 6th Research Symposium, Child Development Center, Children's Hospital Zürich, Au, Switzerland, 10/2016. Oral presentation.

2015 **Annina E. Zysset,** Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. SPLASHY: Zusammenhang zwischen motorischen und kognitiven Fähigkeiten bei Vorschulkindern. Jahrestagung der Gesellschaft für pädiatrische Sportmedizin, Zürich, Schweiz. 02/2015. Oral presentation.

Annina E. Zysset, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. Relationship between motor skills and cognitive functioning in children. 6th Research Symposium of the Child Development Center, Children's Hospital Zürich, Au, Switzerland, 01/2015. Oral presentation.

Poster presentation

2017 **Annina E. Zysset**, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Valentina Ferrazzini, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. Comparison of parental report and objectively measured fundamental motor skills in preschool children: data from SPLASHY. Swiss Society of Pediatrics Annual Congress, St. Gallen, Switzerland, 06/2017. Poster presentation.

Annina E. Zysset, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. Stability and predictive value of motor skills and cognitive functioning in 2 to 6 year old preschool children. SRCD Meeting, Austin, USA, 04/2017. Poster presentation.

2016 **Annina E. Zysset**, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Valentina Ferrazzini, Andrea

H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. The motor skill questionnaire for preschool children (MSQ-P). 6th Research Symposium, Child Development Center, Children's Hospital Zürich, Au, Switzerland, 10/2016. Poster presentation.

Annina E. Zysset, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. Age differences in the relationship between motor and cognitive skills in Swiss preschool children. Jahreskongress SGPP& SGKJPP, Basel, Switzerland, 08/2016. Poster presentation.

2015 **Annina E. Zysset**, Tanja H. Kakebeeke, Nadine Messerli-Bürgy, Kerstin Stülb, Amar Arhab, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Susi Kriemler, Jardena J. Puder, Simone Munsch, Oskar G. Jenni. Age differences in the relationship between motor skills and cognitive functioning in Swiss preschool children. 5th Research Symposium, Child Development Center, Children's Hospital Zürich, Au Switzerland, 10/2015. Poster presentation.

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